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OPTICAL THREAT/LASER COUNTERMEASURES ENGAGEMENT ANALYSIS.(U)
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AFIT/GEP/PH/77-10

OPTICAL THREAT / LASER COUNTERMEASURES ENGAGEMENT ANALYSIS

THESIS

AFIT/GEP/PH/77-10 James R. Penick
Captain USAF

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AFIT/GEP/PH/77-10

OPTICAL THREAT / LASER COUNTERMEASURES ENGAGEMENT ANALYSIS

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by

James R. Penick, B.S.

Captain USAF

Graduate Engineering Physics

December 1977

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Preface

This report is an attempt to analyze an engagement between an aircraft and a ground threat, each of which is using optics in tracking or electronic countermeasures roles. Actually, the report is limited to starting the analysis, which will probably continue far into the future. In limiting the scope of the problem, the atmospheric effects have been ignored. Also, the aircraft has not been allowed to manuever but just flies in a straight path over the threat. This is not realistic, but necessary in order to concentrate on the real problems such as tracking and jamming.

Dusting off and reviving my expertise in FORTRAN programming was a herculean task cheerfully accepted by Mr. William McQuay of the Avionics Laboratory. I would also like to thank Capt. Phil Gordin for his assistance in establishing the direction and scope of this problem.

Special thanks goes to Dr. Shankland for his guidance and direction in pursuing the problem.

I wish to acknowledge my indebtedness to my wife for keeping things under control at home and helping in the preparation of this report.

James R. Penick

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List of Definitions

User Variables

ANGLE . . . . Used in FB4. The solution to the quadratic formula used to determine the point of intercept.

ASPEDX, ASPEDY, ASPEDZ . The speed of the aircraft in the x, y, and z directions. Used in all Fly Bys.

BARK . . . . Used in FB4. Represents a small part of the a and c constants in the quadratic formula used to find the point of intercept.

BITE . . . . Used in FB4. Another step up from BARK in determining the a and c constants.

D . . . . Used in FB4. Represents a change in range. Output of RNORM.

DELAY . . . . Used in FB4. Represents the amount of time needed to fire another missile after one has been fired.

DOG1 . . . . Used in FB4. Represents the a constant in the quadratic formula.

DOG2 . . . . Used in FB4. Represents the c constant in the quadratic formula.

DOG3 . . . . Used in FB4. Represents b^2 in the quadratic formula.

DOG4 . . . . Used in FB4. Represents b in the quadratic formula.

E . . . . Used in FB4. Represents a small change in elevation. Output of RNORM.

EFFRM . . . . Used in FB4. This is the effective range of the missile.

EFFRT . . . . This is the effective range of the tracking radar. Used in FB4.

F . . . . Represents a small change in azimuth and is used in FB4.

HIALT . . . . Variable used in all Fly Bys to simulate detection probability. Divided by aircraft range to arrive at detection probability number.

JFLAG . . . . Used in FB4. This flag is set in SCANT and used to determine if the tracker is detecting the aircraft for the first time. Statistics are collected only when the tracker sees the aircraft for the first time.

KFLAG . . . . Used in FB4. Used in DETECT to determine if detection by the acquisition radar has been continuous.

MFLAG . . . . Used in FB4. Used in DETECT to determine if the aircraft is being detected by the acquisition radar for the first time.

MINEFR . . . . This is the minimum effective range of the missile. Used in FB4.

MFLTT . . . . Used in FB4. This is the missile flight time from launch to intercept.

NACFT . . . . Used in FB3 and FB4. This is the number of aircraft remaining in the simulation. Used as a counter. When 0, the simulation ends.

NACFTI . . . . Used to record the number of aircraft at the beginning of the simulation. Used in FB3 and FB4.

NMISL . . . . Used in FB4. This is the number of missiles the threat can fire at a single aircraft.

NNSURR . . . . Used in FB4. This is the number of aircraft shot down.

NSURR . . . . Represents the number of aircraft that survive. Used in FB4.

PHE . . . . Used in FB4. This is the angle of azimuth used by the tracker to compute the aircraft position and an intercept point.

POSAX,POSAY,POSAZ . . .	Used in all Fly Bys. Represents the aircraft position at TNOW.
POSAXI,POSAYI,POSAZI .	Used in all Fly Bys. This is the initial position of the aircraft.
POSMX,POSMY,POSMZ . . .	Used in FB4. This is the position of the missile at the time of missile-aircraft intercept.
POSTX,POSTY,POSTZ . . .	Used in all Fly Bys. This is the position of the threat.
PRBDET	Used in FB2, FB3, and FB4. Represents the probability of detecting the aircraft with the acquisition radar.
PRBTRK	Used in FB4. This is the probability of detecting the aircraft with the tracking radar.
RVEL	Used in FB4. This is the speed of the aircraft.
SCANR	This is the scan rate of the acquisition radar. Used in FB2, FB3, and FB4.
SCANRT	Used in FB4. This is the scan rate of the tracking radar.
SS(1)	Used in all Fly Bys. This is the only state variable, the aircraft range.
SST	The aircraft range as determined by the tracker. Used in FB4.
TANGLE	This is the masking angle of the horizon. The acquisition radar cannot "see" below this angle due to terrain masking. It is measured with respect to the threat position. Used in FB3 and FB4.
TDETI	Used in FB4. This is the time of initial detection by the acquisition radar. It is reset if the detection is not continuous.
TEFFR	Used in all Fly Bys. This is the effective range of the acquisition radar.

THETA . . . . This is the angle of elevation computed by the tracker. Used in FB4.

TTIME . . . . This represents the total time of continuous detection by the acquisition radar. Used in FB4.

X . . . . A random number generated by DRAND. It is compared to PRBDET to determine if detection has occurred. Used in FB2, FB3, and FB4.

XMISS . . . . Used in FB4. This is the miss distance of the missile.

XMSPED . . . . This is the missile speed. Used in FB4.

Y . . . . A random number generated by RNORM. Used in FB4 to determine if detection has been made by the tracking radar.

GASP Variables

ATRIB(X) . . . . This is a buffer for attribute values being stored in or retrieved from QSET, the file storage area. Used in all Fly Bys.

LFLAG(X) . . . . Used in all Fly Bys. These are the state condition flags.

MSTOP . . . . Used in all Fly Bys. This is GASP indicator which specifies how the simulation will be ended. If MSTOP is read in as a 0, then it must be reset to a negative value to stop the simulation. If read in as a positive value, then the simulation will continue until TNOW reaches the user specified end time, TTFIN.

TNOW . . . . Used in all Fly Bys. This is the current time of the simulation.

Abstract

This report contains data on the construction of a computer model to study a one-on-one engagement. It is built so that parameters in the RF or optical regime can be used. The aircraft flies over the threat, is not allowed to maneuver, and the atmosphere has been ignored.

Fly By 1 introduces the techniques employed by the GASP IV simulation language. The aircraft is detected when it comes within range. In Fly By 2, a more probabilistic determination of detection is used, and the radar scans for the aircraft. Fly By 3 makes 20 runs of the Fly By 2 program and collects statistics on the range of detection. Fly By 4 incorporates a track and fire role into the threat. It shoots down 70% of the aircraft with the parameters used.

The parameters used are not specific to one system, but can be easily changed to reflect a specific system.

The appendices contain results of the programs along with the calculations used to determine an intercept point for the aircraft and missile.

OPTICAL THREAT / LASER COUNTERMEASURES ENGAGEMENT ANALYSIS

I. Introduction

During the Arab-Israeli War in 1973, the use of optically guided surface-to-air missiles (SAMS) and anti-aircraft artillery (AAA) took much of the world by surprise. It was so effective, when combined with conventional systems, that the Arabs were able to seriously challenge Israeli Air superiority for the first time.

The analysis of the problems faced by the Israeli Air Force led USAF planners to the conclusion that in the future, penetrating aircraft may face optically and/or electro-optically directed weapons. Numerous programs have since been funded to develop optical receivers and countermeasures devices. One of the problems encountered was the need for a generic computer model to analyze the engagement of an aircraft configured with the proposed optical countermeasures equipment against threats using optically directed weapons. The purpose of this report is to develop such a computer model.

The model has been limited to an engagement of one aircraft against one threat. Information on the various countermeasures devices being considered or developed to be used in this role was not available when this report was written. Information on the threats against which these devices could

be used was also not available when this report was written. The above information will soon be available at the Air Force Avionics Laboratory Library and is mostly classified. For these reasons, the parameters used in this report do not reflect a specific countermeasure or threat device but rather a combination of generally realistic values. Atmospheric propagation has been ignored due to time constraints.

The initial step in the problem was an extensive literature search. Various documents were obtained to aid in the preparation of this report. A Defense Documentation Control Center search was initiated to obtain technical reports pertaining to the problem. Again, these documents were not available or their classification limited their use to generalities and not specific data.

The primary problem is focused around the computer model itself. It was required that this model be flexible enough to allow incorporation at a later time of those parts of the problem not covered in this report or which need expanding. Also, it was necessary that the model be flexible enough to allow changes in threat and OCM parameters to simulate any of the threat systems and proposed receivers and jamming devices.

For these reasons, the GASP IV simulation language was chosen as the simulation base. It combines the advantages of being written in FORTRAN, immediately available, and modular in form. Learning to use GASP IV was a major task in this project.

II. The Scenario and GASP IV

Description of the Scenario

The scenario involves one aircraft and one threat. The purpose is to analyze their engagement by collecting statistics on various events such as aircraft entry into the threat area and missile firing. The final goal is to obtain results on aircraft survivability. All distances are measured in meters. The aircraft initial position is defined by POSAXI, POSAYI, and POSAZI in the x, y, and z directions, with the z parameter representing aircraft altitude. The threat position is defined by POSTX, POSTY, and POSTZ. Throughout this simulation, the threat has been located at the origin.

The aircraft flies a straight path which leads directly over the threat. Aircraft maneuvers were not incorporated due to time constraints. Also, the aircraft velocity and altitude were held constant in each simulation.

The threat is given an acquisition, tracking, and firing role. Each of these functions has limitations which are represented by a sphere centered at the threat. The outer surface of the sphere represents the limit of that particular function. As an example, the limit of an acquisition radar is represented in Fig. 1 on page 4. The aircraft is considered to be in range of the acquisition radar when it enters this sphere.

Each engagement begins with the aircraft at the periphery of acquisition. The aircraft then moves through the threat area and passes over the site. When the aircraft

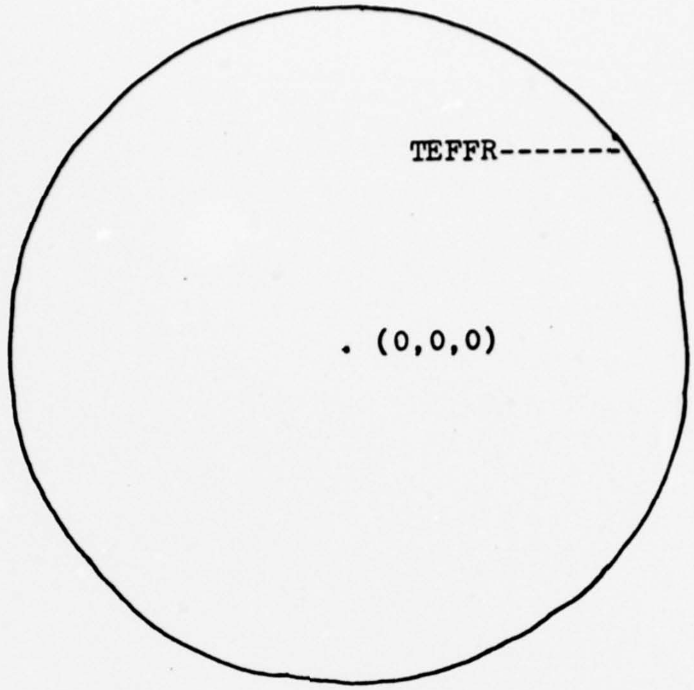


Fig. 1. Effective Range of Acquisition Radar

leaves the threat sphere of influence the simulation is ended.

Fly By

In planning this project, it was decided to break the problem up into several stages to be accomplished one after the other. Each of these pieces is a complete program in itself. The name Fly By has been given to each, followed by a number to designate where it appears in the overall project. Fly By 1 is the initial program. Each succeeding program incorporates the preceding ones and adds a new dimension to the problem. All of the Fly By programs are described in detail in Chapter III.

GASP IV

To speed up the process of building the model, a simulation language was needed to provide structure and terminology. GASP IV is such a simulation language. The programs built using GASP IV are useful as both models and analysis tools (Ref 1:1).

GASP provides the user with a philosophy and a programming language. Modeling concepts are built-in and are linked to the user through FORTRAN routines that can be easily learned and used. Other advantages are: GASP is FORTRAN based and requires no separate compiling system; it is modular; it is easy to learn because it is FORTRAN based; it is easily modified to particular applications; and it can be used for discrete, continuous, or combined simulation (Ref 1:3).

GASP uses an entity-attribute approach in modeling. Entities are those things in a system such as people, equipment, and raw materials. Attributes are the characteristics of these entities. Entities having a common attribute are grouped into files.

In simulating a system, one desires to learn something about the behavior and performance characteristics of the system. This is done by reproducing the activities in which the entities engage. The system has certain states defined in terms of the numeric values assigned to attributes in the system. Simulation causes the system to move from state to state and is the dynamic portrayal of the states of a system

over time. The two most important activities associated with simulation are the identification of the entities and their attributes, and the coding of the attribute values into characteristic system states (Ref 1:5).

A few words about discrete, continuous, and combined simulation are necessary. As a model moves from state to state, entities engage in activities which change the states. These activities are marked at beginning and end by events. Take as an example an elevator. Consider the events "elevator starts travel" and "elevator arrives at next floor". In a discrete model, the time of arrival of the elevator at the next floor would be known from the event "elevator starts travel". It is a given value, a discrete value, based on the time at which the elevator started moving. In a continuous model, however, the time between floors would not be deterministic. The functions in the equation of motion of the elevator would have variations which might reflect the number of people on board, the direction of travel, or the number of serviceable elevators. The time between floors would be variable and depend on these and other factors. Such attributes, which are based on a continuous representation of the dynamics of the attribute, are called state variables in GASP (Ref 1:8).

When the dependent variables change discreetly at specified points in simulated time, discrete simulation is occurring. When they change continuously, a continuous simulation is the result. And when the dependent variables

change continuously with possible discrete jumps superimposed, the result is defined as a combined simulation (Ref 1:8).

The GASP philosophy is explained in Chapter 2 of reference 1. The reader will also find printouts and flowcharts of the GASP subroutines. Numerous examples are used to explain to the user the various aspects of GASP simulation.

The most important of the GASP subroutines are those written by the user. These routines will be mentioned repeatedly in the following chapters. Their purposes are outlined below.

Subroutine INTLC is used to initialize non-GASP variables, state variables, and the derivatives of state variables, if any. SCOND is the subroutine which determines if a state-event has occurred. When either a state or time-event occurs, subroutine EVNTS is used to determine what action to take for each event. It also checks to see which state-event has occurred. Subroutine OTPUT provides a means for the user to obtain output in addition to that normally provided by GASP. Two other subroutines are user written but were not used in this project. These are UERR, which allows specific information to be printed for errors, and SSAVE, which collects data for the user to print out. Dummy subroutines were used for UERR and SSAVE throughout the simulation.

GASP Subroutines

All user variables have been listed and defined on

pages v-viii. Those GASP variables necessary for understanding the discussions in this report are listed and defined on page viii.

There are three GASP subroutines and three GASP functions that are used frequently in the user written subroutines described in this report. They are defined and their functions explained in the following paragraphs.

Subroutine COLCT(XX,ICLCT) collects sample data on the variable SS(XX). It calculates the mean, standard deviation of the mean, standard deviation, coefficient of variation, minimum, maximum, and the number of times the variable was observed. All this information is printed out in tabular form at the end of the simulation (Ref 1:133).

Subroutine HISTO(XX,IHIST) tabulates the number of times a variable is within a prescribed cell limit. It also calculates observed, relative, and cumulative frequency for each cell. At the end of the simulation, it prints out a plotted histogram of the relative and cumulative frequency of observations (Ref 1:138).

Each of these subroutines can be used in several modes, depending on the value of ICLCT and IHIST used. The computation and reporting mode is the one described above and the only one used in this report. This mode is indicated by setting positive values in ICLCT and IHIST.

The other subroutine is FILEM(IFILE), which is used to store attributes in IFILE. In this report, FILEM is used to change the attributes of time-events.

Two of the functions are random number generators. RNORM(IPAR,ISTRM) is a normal deviate generator which uses the random number stream ISTRM and parameters from parameter set IPAR. DRAND(ISTRM) uses random number stream ISTRM to generate a uniform number.

The last function is KROSS(IKRSG,IKRSD,CMULT,CADD,LDIR, TOL). This function locates and specifies state conditions and returns a coded value indicating whether certain conditions have been met. IKRSG is the index of the crossing variable. In this report, it will always be a 1, which indicates that the crossing variable is SS(1), the aircraft range. There is no crossed variable, so IKRSD will always be 0. This value is multiplied by CMULT. The result is then added to CADD to obtain a final value with which to compare the crossing variable. LDIR and TOL indicate the direction and tolerance of the crossing (Ref 1:121).

When function KROSS is called, there are five possible values assigned to the corresponding LFLAG. A +2 value indicates that a positive crossing has occurred outside the tolerance. A +1 value indicates a positive crossing within tolerances, while a 0 indicates no crossing at all. Values of -2 and -1 indicate negative crossings outside tolerance and within tolerance, respectively.

III. The Fly By Programs

Philosophy

The objectives of each of the Fly By programs is different. In FB1, the primary task was learning to use GASP IV. For this reason, there is no actual detection in FB1. The aircraft is assumed detected as soon as it enters the threat range. In FB2, FB3, and FB4, however, the detection and tracking of the aircraft becomes probabilistic.

The primary variable in determining a probability of detection or tracking in an aircraft-ground engagement is the aircraft range from the threat. Thus, SS(1) is used in each of the probabilities computed. But there are other parameters which affect the probabilities. Some of these are radar power, aircraft signature, and weather in the optics regime. In this simulation, these parameters are not included individually, but are combined into one number, HIALT. Time constraints and the desire to keep this report unclassified meant that HIALT was not calculated, but simply selected to give a realistic probability distribution to the detection and tracking functions.

In determining the probability, HIALT is divided by range. The resulting value, PRBDET or PRBTRK, is then compared with 1. The value is then compared with a randomly selected number from a 0 to 1 uniform distribution. If the value is less than or equal to the random number, then a yes condition results. This means the aircraft has been detected or that the tracking device has locked on.

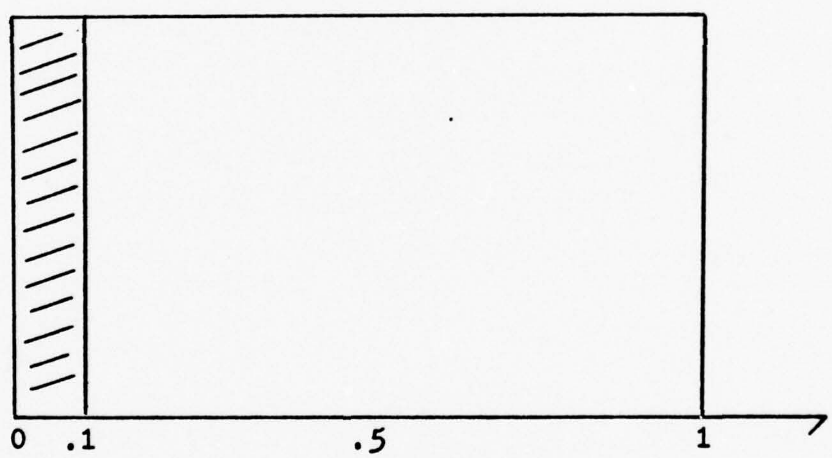
As an example, assume an aircraft at TEFFR of a threat. Also assume the following values apply:

HIALT=5000.0
TEFFR=50000.0

The probability of detection on the initial scan is given

HIALT/SS(1)=.10

Thus, there is a 10% probability of detection on the first pass. To determine if detection occurs, a random number is selected. If it falls within the shaded area of the graph below, then the aircraft is detected. If not, detection does not occur, and the program continues.



It is possible for the aircraft to pass the site and not be detected, but only if the aircraft altitude is greater than HIALT. Assume the aircraft is moving 500m/2s scan, that is it moves 500m between scans. Then the probability of it not being detected in the first 10 scans with the

above variable values is given by

$$P_{nd} = \prod_{i=0}^{10} (1\text{-HIALT}/(SS(1)-500i))$$

$$= 36.8\%$$

In FB2, the probability of detecting an aircraft on the first scan is 100%. In FB3 this has been made more realistic by changing the value of HIALT. In this program, the probability of detection is 2.79% on the first scan. This goes to 100% when the aircraft is 5000m from the threat. In FB4, the probabilities are altered so that detection on the first scan occurs 31.4% of the time. The probability of lock-on by the tracker on its first scan is 95%.

The purpose of these distributions is not to show actual detection and tracking probabilities, which would require the radar range equation. The purpose is to show that the program is capable of determining the probabilities based on the data input of the user.

Fly By 1

The purpose of the Fly By 1 program is to fly an aircraft through a threat area on a straight path. The range from the aircraft to the threat is computed and constantly updated. When the aircraft enters the effective range of the acquisition radar, the range is printed. The simulation ends when the aircraft passes out of range of the acquisition radar. A general flowchart of FB1 is shown in Fig. 2 on page 13. The scenario depicted in FB1 is shown in Fig. 3

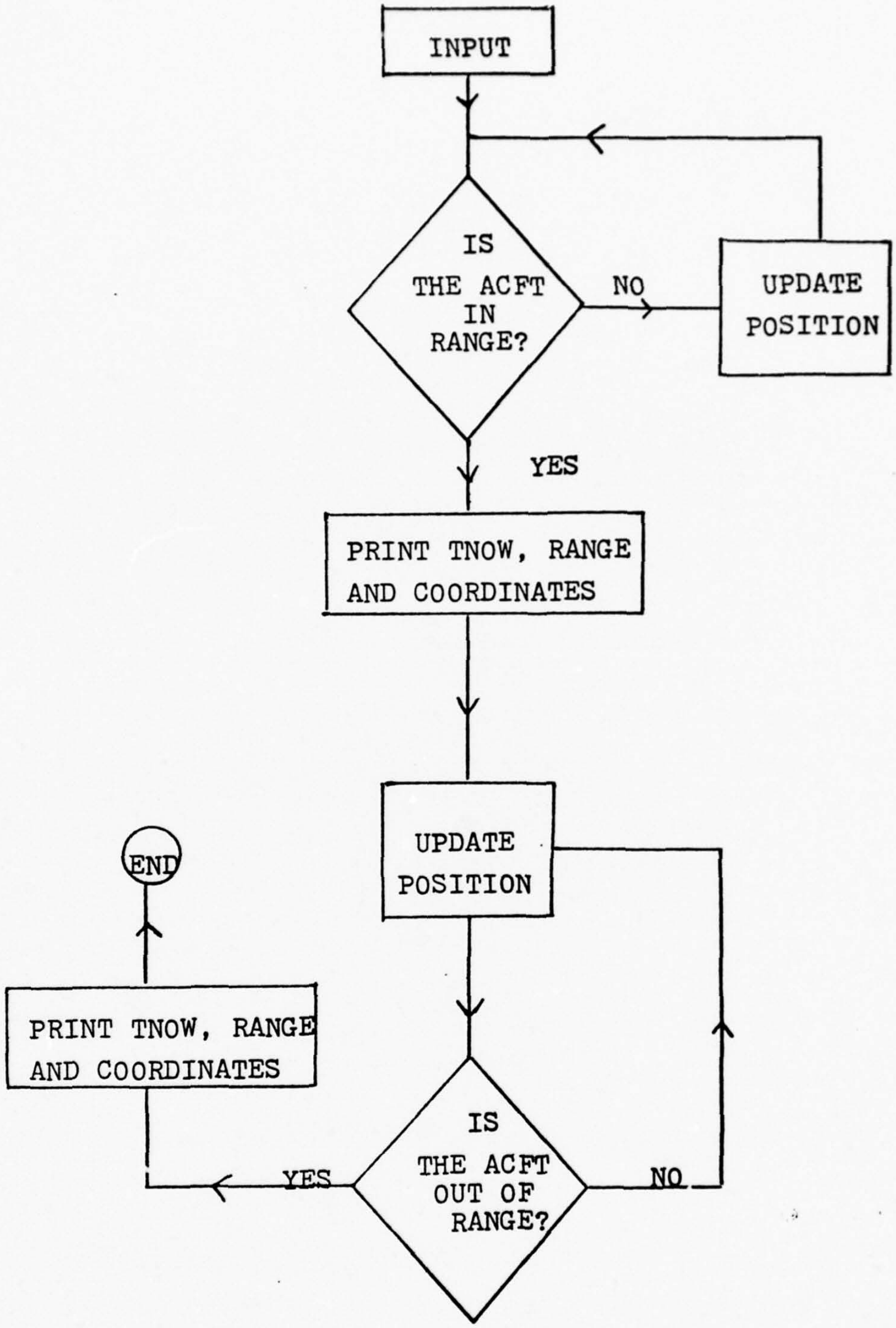


Fig. 2 A General Flowchart of FB1

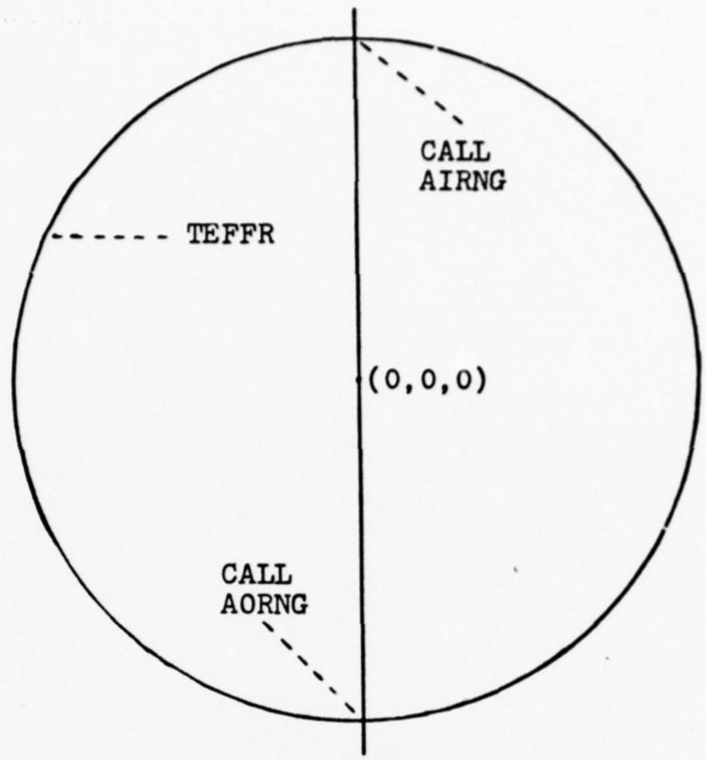


Fig. 3. FB1 Scenario

above.

PROGRAM FLYBY1 starts the simulation by setting the cardreader and printer numbers. It then calls GASP, which initializes GASP variables and reads in the data cards. From GASP, the program goes to INTLC, which initializes all FB1 variables that require initialization. A partial listing of INTLC, showing those variables initialized, follows. Only common blocks and end statements will be omitted from the listings found in this report.

```
POSAXI=0.0
POSAYI=11000.0
POSAZI=5000.0
```

```
POSAX=POSAXI
POSAY=POSAYI
POSAZ=POSAZI
ASPEDX=0.0
ASPEDY=-400.0
ASPEDZ=0.0
TEFFR=10000.0
POSTX=0.0
POSTY=0.0
POSTZ=0.0
```

Once initialization has been accomplished, INTLC returns the program to GASP, which then calls STATE. In STATE, TNOW is used to compute the aircraft position and range. This is accomplished with the following statements:

```
POSAX=POSAXI+ASPEDX*TNOW
POSAY=POSAYI+ASPEDY*TNOW
POSAZ=POSAZI+ASPEDZ*TNOW
SS(1)=(POSAX**2+POSAY**2+POSAZ**2)**.5
```

The first three statements take the initial position of the aircraft and update it by multiplying the speed along each direction by the total time of travel in that direction. The last statement then computes the aircraft range from the threat.

On return from STATE, GASP calls SCOND, which checks to see if a state condition has occurred. In this simulation, there are two state-events. These are aircraft penetration into the threat area and aircraft withdrawal from the threat area. Checking for these two events is accomplished in SCOND by the following statements:

```
LFLAG(1)=KROSS(1,0,0.0,10000.0,+1,200.0)
LFLAG(2)=KROSS(1,0,0.0,10000.0,-1,200.0)
```

In the first statement, the aircraft range SS(1) is compared with 10000.0m to determine if a positive crossing within a tolerance of 200.0m has occurred. When this crossing occurs, LFLAG(1) is set to a value of +1, indicating that the aircraft is leaving the threat area. In the second statement, SS(1) is compared with 10000.0m to see if a negative crossing has occurred within 200.0m. If neither state-event has occurred, GASP updates TNOW and returns to STATE to begin the process again. This continues until one of the state-events occurs. At that point, GASP calls EVNTS.

The task of EVNTS is to determine which state or time-event has occurred. If the event is a time-event, the attribute ATRIB(2) is checked to see which of the time-events has occurred. There are no time-events in FB1, so a detailed explanation of them will be deferred until the discussion of FB2. For state-events, EVNTS uses the following statements to determine which has occurred and what action to take:

```
IF (LFLAG(1)=+1) CALL AORNG
IF (LFLAG(2)=-1) CALL AIRNG
```

The first statement checks to see if LFLAG(1)=+1. If yes, then the aircraft is out of range and AORNG is called. The second statement checks to see if LFLAG(2)=-1, indicating the aircraft is within range. If yes, then AIRNG is called. The two state-events are mutually exclusive. They cannot occur simultaneously unless an error has been made. Also, when EVNTS is called, one of the state-events has occurred

and either AORNG or AIRNG must be called.

Subroutine AIRNG is called when the aircraft comes within range of the acquisition radar. It computes the position of the aircraft at the time of the crossing and prints the time, coordinates, and range of the crossing event. It does this with the following statements:

```
      POSAX=POSAXI+ASPEDX*TNOW
      POSAY=POSAYI+ASPEDY*TNOW
      POSAZ=POSAZI+ASPEDZ*TNOW
      PRINT(6,105) TNOW,POSAX,POSAY,POSAZ,SS(1)
  105 FORMAT("TNOW IS",F15.2 / "COORDINATES ARE",3F15.2
            / "RANGE I
     1S",F15.2)
```

Subroutine AORNG is called when a positive crossing occurs, indicating the aircraft has passed out of range of the radar. The time, position, and range of this event are then printed. The simulation is then ended by resetting the value of MSTOP to a negative value. The statements which accomplish this task are the following:

```
      PRINT(6,105) TNOW,POSAX,POSAY,POSAZ,SS(1)
  105 FORMAT("TNOW IS",F15.2 / "COORDINATES ARE",3F15.2
            / "RANGE I
     1S",F15.2)
      MSTOP=-1
```

Once AORNG has been called, the simulation is ended the next time GASP gains control. All GASP and user information requested is then printed out. A sample of the printout from FB1 is listed in Appendix A. These results are discussed in Chapter V.

Fly By 2

In FB1, the aircraft was assumed detected when it crossed the TEFFR. In FB2, a more realistic detection method is developed. The radar is allowed to begin scanning for the aircraft when the aircraft crosses the TEFFR. The probability of the aircraft being detected by the radar is now a function of range to the aircraft and an assigned threat effectiveness number, HIALT. This introduces an inverse range randomness. The HIALT variable incorporates all the parameters which would normally be used in the radar range equation. For FB2, HIALT was chosen to give a realistic chance of detection at TEFFR.

Other refinements over FB1 appear in the printout. Headings have been included to tell when the aircraft penetrates, withdraws, or is detected. The time, coordinates, and range of each of these events is also printed out. A general flowchart of FB2 is shown in Fig. 5 on page 20. In Fig. 4, shown on page 19, the FB2 scenario is depicted.

PROGRAM FLYBY2 starts the simulation by setting the cardreader and printer numbers. It then calls GASP, which reads in the data cards and initializes GASP variables. GASP then calls INTLC, which initializes all non-GASP variables. The statements which accomplish this are the following:

```
POSAXI=0.0
POSAYI=11000.0
POSAZI=5000.0
POSAX=POSAXI
POSAY=POSAYI
```

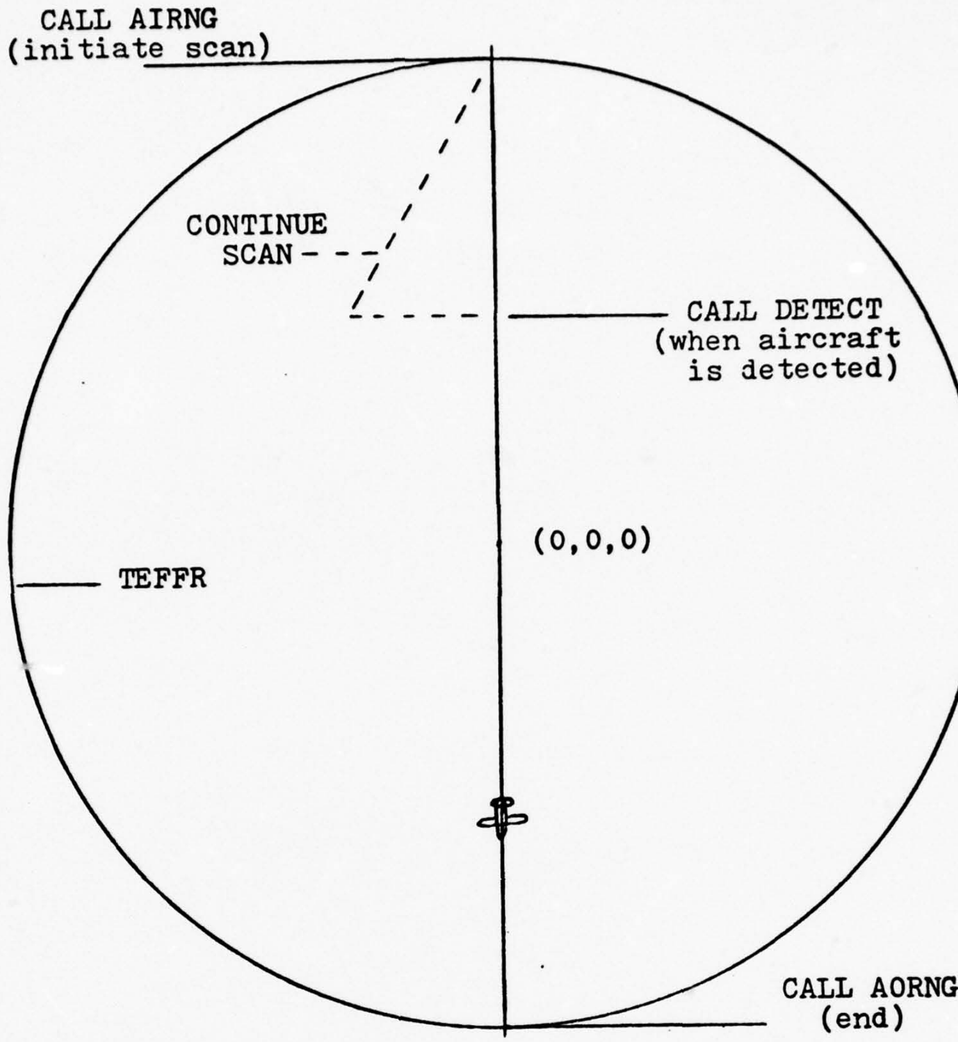


Fig. 4. FB2 Scenario

```
POSAZ=POSAZI
ASPEDX=0.0
ASPEDY=-400.0
ASPEDZ=0.0
TANGLE=.0349
HIALT=10000.0
TEFFR=POSAZ/SIN(TANGLE)
TEFFR=AMIN1(TEFFR,10000.0)
POSTX=0.0
POSTY=0.0
POSTZ=0.0
SCANR=10.0
```

As can be seen, there are a few changes over FB1. TANGLE is

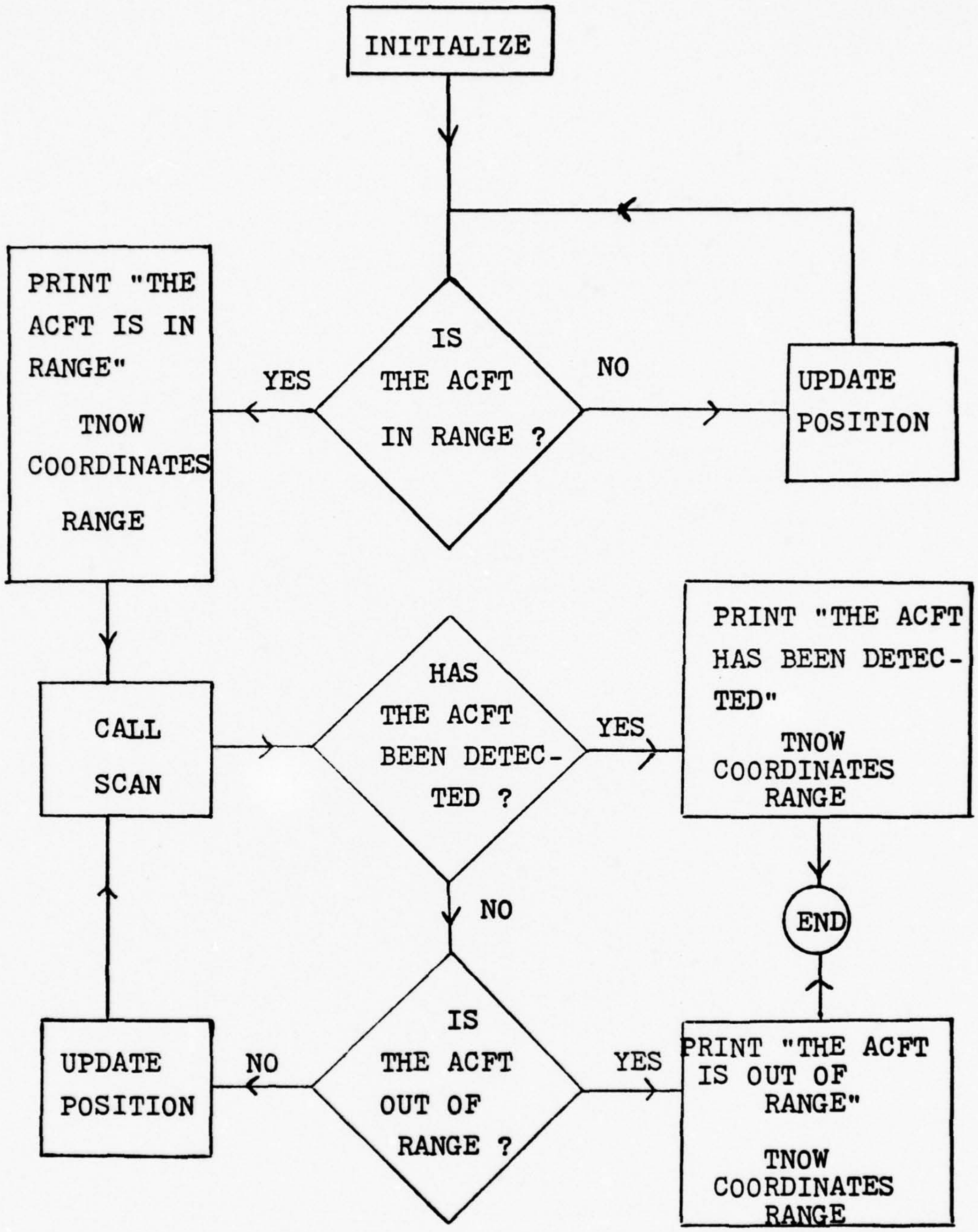


Fig. 5. A General Flowchart of FB2.

the terrain masking angle in radians. It is used to determine how far above the horizon the radar can "see", assuming a flat earth. The threat effective range is calculated from this angle and then set equal to the minimum of the actual range of the radar and its range at the aircraft altitude to be considered in this simulation. Another change is SCANR, which represents the sweep rate of the radar in seconds.

Once initialization has been accomplished, INTLC returns to GASP, which then calls STATE. In STATE, as in FB1, TNOW is used to compute the aircraft position and range. The statements used to accomplish this are the same used in FB1. They are listed on page 15.

On return from STATE, GASP calls SCOND and a check is made for state conditions. As in FB1, aircraft penetration and aircraft withdrawal are the only state-events. The following statements are used in SCOND to check for these events:

```
LFLAG(1)=KROSS(1,0,0.0,TEFFR,+1,200.0)
LFLAG(2)=KROSS(1,0,0.0,TEFFR,-1,200.0)
```

In the first statement, SS(1) is compared to the variable TEFFR to determine if a positive crossing has occurred. This would indicate aircraft withdrawal. In statement two, a check for aircraft penetration is made by comparing SS(1) and TEFFR for a negative crossing. The tolerance in both cases is 200.0m, the same as in FB1. If neither state-event has occurred, GASP updates TNOW and returns to STATE. This process continues until an event is detected in SCOND and

GASP calls EVNTS.

EVNTS determines which state or time-event has occurred. The argument IX in subroutine EVNTS(IX) is used to distinguish time and state-events. All time-events are initialized with at least two attributes. ATRIB(1) is the time of occurrence of the event, while ATRIB(2) is the event-code of that time-event. Initialization also includes the setting of the state-event code, IIEVT, which is unique from all ATRIB(2) time-event identifiers. The IX argument is set by GASP. If TNOW corresponds to a time-event occurrence time, ATRIB(1), then IX is set to the code for that event, ATRIB(2). If SCOND detects a state-event, GASP sets IX to IIEVT. A partial listing of EVNTS appears below:

```
    GO TO (101,102),IX
102 CALL SCAN
    GO TO 110
101 CONTINUE
    IF (LFLAG(2).EQ.-1) CALL AIRNG
    IF (LFLAG(1).EQ.+1) CALL AORNG
110 RETURN
```

The computed GO TO statement separates time-events from state-events. In FB2, the state-event code is a 1 while the only time-event is identified by 2. The time of occurrence of a time-event is determined by ATRIB(1) of the time-event. This attribute is initially set on data cards and can be changed during the simulation. When TNOW=ATRIB(1) of any time-event, GASP sets IX-ATRIB(2) of the same time-event. When a state-event is detected in SCOND, GASP sets IX to the state-event code.

If the event is a time-event, IX=2 causes EVNTS to call SCAN. In this case, there is no need to check for state-event flags, so a return to GASP is initiated after return from SCAN. If the event is a state-event, then all flags are checked to see which event has occurred and what action to take. For aircraft penetration, LFLAG(2)=-1 and AIRNG is called. For aircraft withdrawal, LFLAG(1)=+1 and AORNG is called. The three subroutines which EVNTS can call are discussed in the following order: AORNG, AIRNG, and SCAN.

As noted, AORNG is called for aircraft withdrawal. The time, position, and range of aircraft withdrawal are printed and the simulation ended using the statements listed below.

```
      PRINT*," THE AIRCRAFT IS OUT OF RANGE "
      PRINT(6,105) TNOW,POSAX,POSAY,POSAZ,SS(1)
  105 FORMAT(" TNOW IS ",F15.2 / " COORDINATES ARE ",
           3F15.2 / " RANGE I
     1S ",F15.2)
      MSTOP=-1
```

Subroutine AIRNG has a few changes from FB1 due to the time-event. A partial listing of AIRNG appears below:

```
      PRINT*," THE AIRCRAFT IS IN RANGE "
      PRINT(6,105) TNOW,POSAX,POSAY,POSAZ,SS(1)
  105 FORMAT(" TNOW IS ",F15.2 / " COORDINATES ARE ",
           3F15.2 / " RANGE I
     1S ",F15.2)
      ATRIB(1)=TNOW
      ATRIB(2)=2.0
      CALL FILEM(1)
```

The first print statement just tells the user that the aircraft is in range. The time, position, and range of the event are then printed. In addition, since the aircraft is

in range, the radar can start scanning. Thus, the time of the event SCAN is set to TNOW and its identifier to 2.0. GASP subroutine FILEM(1) is used to file the changed attributes in file 1. Immediately upon return from AIRNG, GASP notes that ATRIB(1) for time-event number 2 is equal to TNOW. It then calls EVNTS with IX=2 and EVNTS calls SCAN.

The purpose of SCAN is to look at the aircraft at specified intervals and determine if the aircraft has been detected. The statements used to accomplish this are the following:

```
PRBDET=AMIN1(HIALT/SS(1),1.)
X=DRAND(1)
IF (X.LE.PRBDET) CALL DETECT
ATRIB(1)=TNOW+SCANR
ATRIB(2)=2.0
CALL FILEM(1)
```

The first statement determines the probability of detection by dividing HIALT by SS(1) and taking the smallest of this value and 1. The purpose of the next statement is to take a random number X from the GASP generator DRAND. X is then compared with the PRBDET number. If it is greater than PRBDET, then detection has not occurred. The time of event SCAN, ATRIB(1), is set to TNOW+SCANR, which means the radar must sweep before trying to detect again. ATRIB(2) is also reset and both values put in file 1 by FILEM.

If X is less than or equal to PRBDET, then detection has occurred and DETECT is called. A listing of the statements used in DETECT follows:

```
      PRINT*," THE AIRCRAFT HAS BEEN DETECTED "
      PRINT(6,105) TNOW,POSAX,POSAY,POSAZ,SS(1)
  105 FORMAT(" TNOW IS ",F15.2 / " COORDINATES ARE ",
            3F15.2 / " RANGE I
     1S ",F15.2)
      MSTOP=-1
```

The fact that the aircraft has been detected is first printed, and then the time, position, and range of the detection. The simulation is ended by setting MSTOP=-1.

It is important to note that if the aircraft is detected, it is not allowed to continue out of range. Either DETECT or AORNG can be called in FB2, but never both. Results of the FB2 program are listed in Appendix A and discussed in Chapter V.

__Fly By 3__

The purpose of the Fly By 3 program is to make a specified number of runs with FB2, collect statistics on each run, and then print the final results of all the runs. It was determined that the way to do this was to reinitialize each run at the point where FB2 had been ended. The counter NACFT is set in PROGRAM FLYBY3 to determine how many runs will be made. Each run is a FB2 program, with certain changes to reflect more realistic parameters, collect statistics, and to continue or stop according to the counter NACFT. For this reason, only those changes made to FB2 will be noted and explained. All other subroutines and statements are the same as in FB2. A general flowchart of FB3 is shown in Fig. 6 on page 26.

There are few changes to INTLC. Most of these reflect

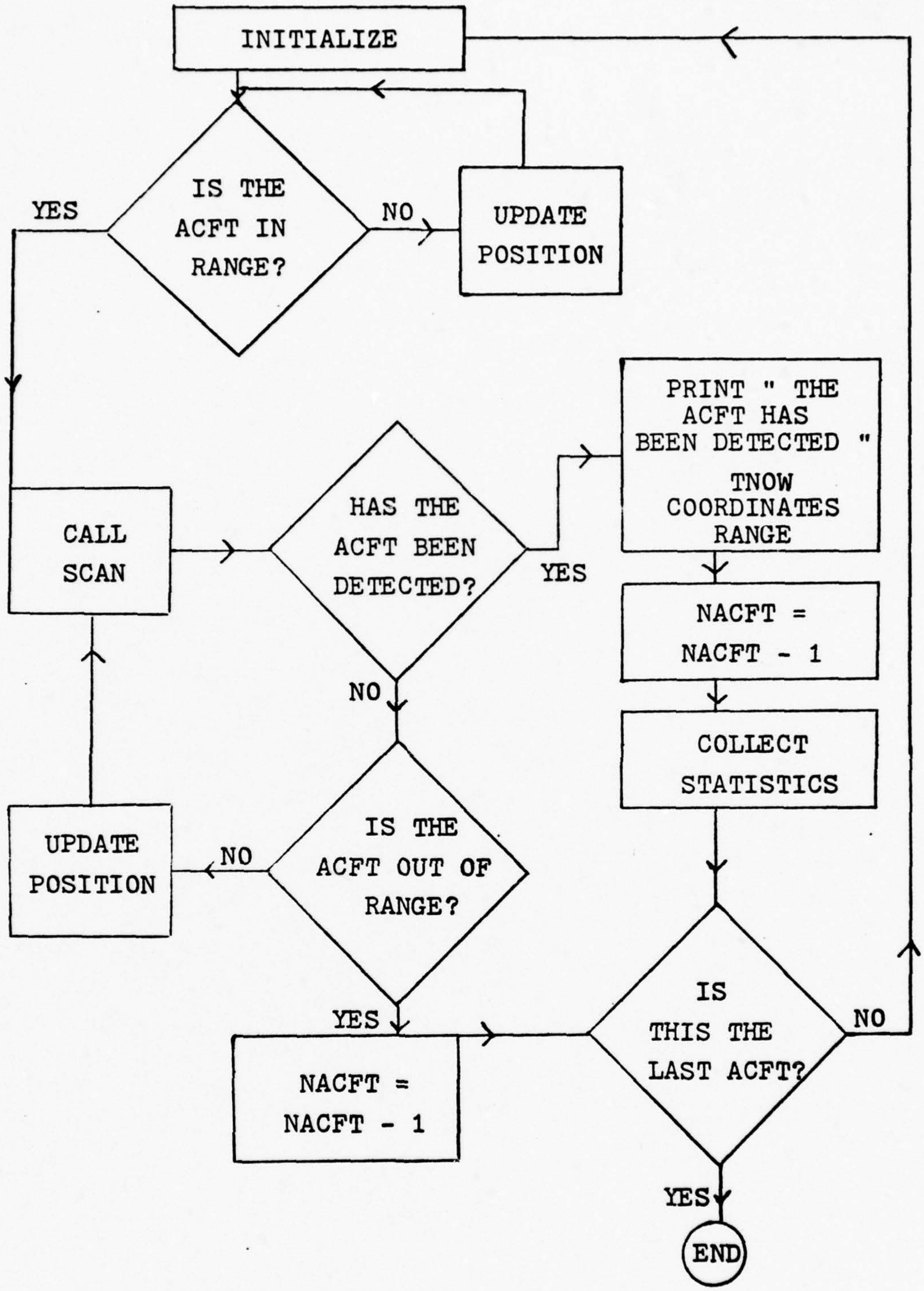


Fig. 6. A General Flowchart of FB3

changes to more realistic numbers. These new statements are shown below:

```
     TNOW=0.0
     HIALT=4000.0
     POSAYI=42000.0
     ASPEDY=-200.0
     TEFFR=AMIN1(TEFFR,40000.0)
     SCANR=2.0
```

The first statement is crucial in that it resets the time when INTLC resets the aircraft to its initial position.

AORNG is the next subroutine which has been changed from FB2. A listing of AORNG is shown below:

```
     PRINT*," THE AIRCRAFT IS OUT OF RANGE "
     ATRIB(1)=1.E20
     ATRIB(2)=2.0
     CALL FILEM(1)
     NACFT=NACFT-1
     IF (NACFT.EQ.0) GO TO 110
     CALL INTLC
     GO TO 111
 110 MSTOP=-1
 111 RETURN
```

First, the flag " THE AIRCRAFT IS OUT OF RANGE " is printed. This means that the aircraft can no longer be detected. To stop the detection process, the time of occurrence of SCAN is set far into the future. Next, the number of aircraft is reduced by 1. If there are no aircraft remaining, the simulation is ended by setting MSTOP=-1. If the counter NACFT is not 0, however, AORNG calls INTLC to begin the simulation over with a new aircraft. No statistics are collected on aircraft withdrawals in FB3.

The only other subroutine which is different from FB2

is DETECT. A listing of this subroutine follows:

```
     PRINT*," THE AIRCRAFT HAS BEEN DETECTED "
     PRINT(6,105) TNOW,POSAX,POSAY,POSAZ,SS(1)
 105 FORMAT(" TNOW IS ",F15.2 / " COORDINATES ARE ",
         3F15.2 / " RANGE I
    1S ",F15.2)
     ATRIB(1)=1.E20
     ATRIB(2)=2.0
     CALL FILEM(1)
     CALL HISTO (SS(1),1)
     CALL COLCT (SS(1),1)
     NACFT=NACFT-1
     IF (NACFT.EQ.0) GO TO 700
     CALL INTLC
     GO TO 110
 700 MSTOP=-1
 110 RETURN
```

The fact that the aircraft has been detected is first noted by a print statement, and then the time, position, and range of detection is printed. Since detection is as far as the program goes with each aircraft, the next step is to stop scanning this aircraft, reinitialize, and go on to another aircraft, if any. To stop the SCAN subroutine from being called again, its time of next occurrence is set far into the future. HISTO and COLCT are then used to collect statistics on the range of detection. The number of aircraft is reduced by 1 and if any remain, a call to INTLC starts the simulation over. If there are no more aircraft, MSTOP is set to a negative value to stop the simulation.

When the simulation is ended, GASP prints out the required data. In FB3, COLCT will give various parameters of the range of detection, such as minimum and maximum values. HISTO prints out a histogram showing where the aircraft was detected on each run. A discussion of the results of FB3

can be found in Chapter V. A sample of these results is given in Appendix A.

Fly By 4

Fly By 4 is the last, and therefore the most complicated, of the Fly By programs. There are several additions over its predecessor, FB3. Most important of these is the addition of another radar to the threat. This is a tracking device. It tracks the aircraft, computes its position, and then calls subroutine FIREM to fire missiles at the target. In addition to collecting statistics on range of detection, the program also collects statistics on the range at which the tracking device "locks-on" and the range at which a missile is fired at the aircraft. Other output includes the number of surviving aircraft and the number shot down. The FB4 scenario is shown in Fig. 7 on page 30. A general flowchart of FB4 is shown in Fig. 8 on pages 32-34.

PROGRAM FLYBY4 starts off the simulation with the following statements:

```
NCRDR=5
NPRNT=6
NACFT=20
NACFTI=NACFT
NSURR=NACFT
CALL GASP
CALL EXIT
```

The cardreader and printer numbers are set first, and then the counters NACFT, NACFTI, and NSURR. The main program then calls GASP.

After initializing GASP variables and reading in all

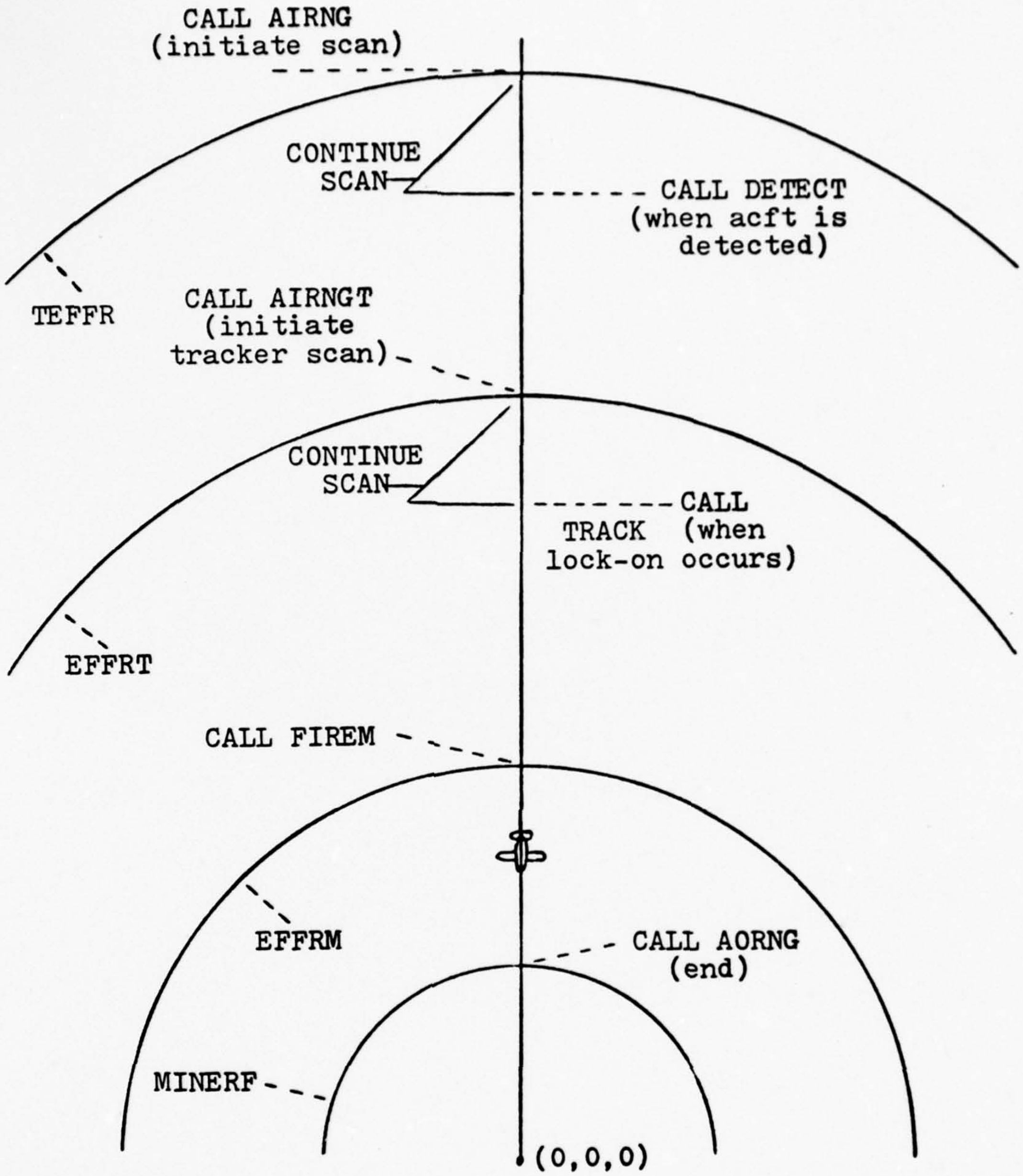


Fig. 7. FB4 Scenario

data cards, GASP calls INTLC. A partial listing of the statements in this subroutine follows:

```
MFLAG=1
KFLAG=0
JFLAG=1
```

```
EFFRT=50000.0
MINEFR=14000.0
EFFRM=40000.0
TNOW=0.0
POSAXI=0.0
POSAYI=401000.0
POSAZI=5000.0
POSAX=POSAXI
POSAY=POSAYI
POSAZ=POSAZI
ASPEDX=0.0
ASPEDY=-222.0
ASPEDZ=0.0
HIALT=4000.0
TANGLE=.0349
TEFFR=POSAZ/SIN(TANGLE)
TEFFR=AMIN1(TEFFR,400000.0)
POSTX=0.0
POSTY=0.0
POSTZ=0.0
SCANR=2.0
SCANRT=.5
NMISL=2
DELAY=0.0
RVEL=-222.0
XMSPED=444.0
```

The three flags MFLAG, KFLAG, and JFLAG are used to determine if certain conditions have been met. They will be described in detail in the descriptions of the subroutines where they are used. The effective range of the tracking device, minimum effective range of the missile, and the missiles maximum effective range are read in as EFFRT, MINEFR, and EFFRM, respectively. Other new parameters are DELAY, a timing device used in FIREM; NMISL, the number of missiles the threat is allowed to fire at each aircraft; RVEL, the speed of the aircraft; and XMSPED, the missile speed. After initialization, INTLC returns to GASP, which then calls STATE.

Subroutine STATE is used in FB4 exactly the same as in

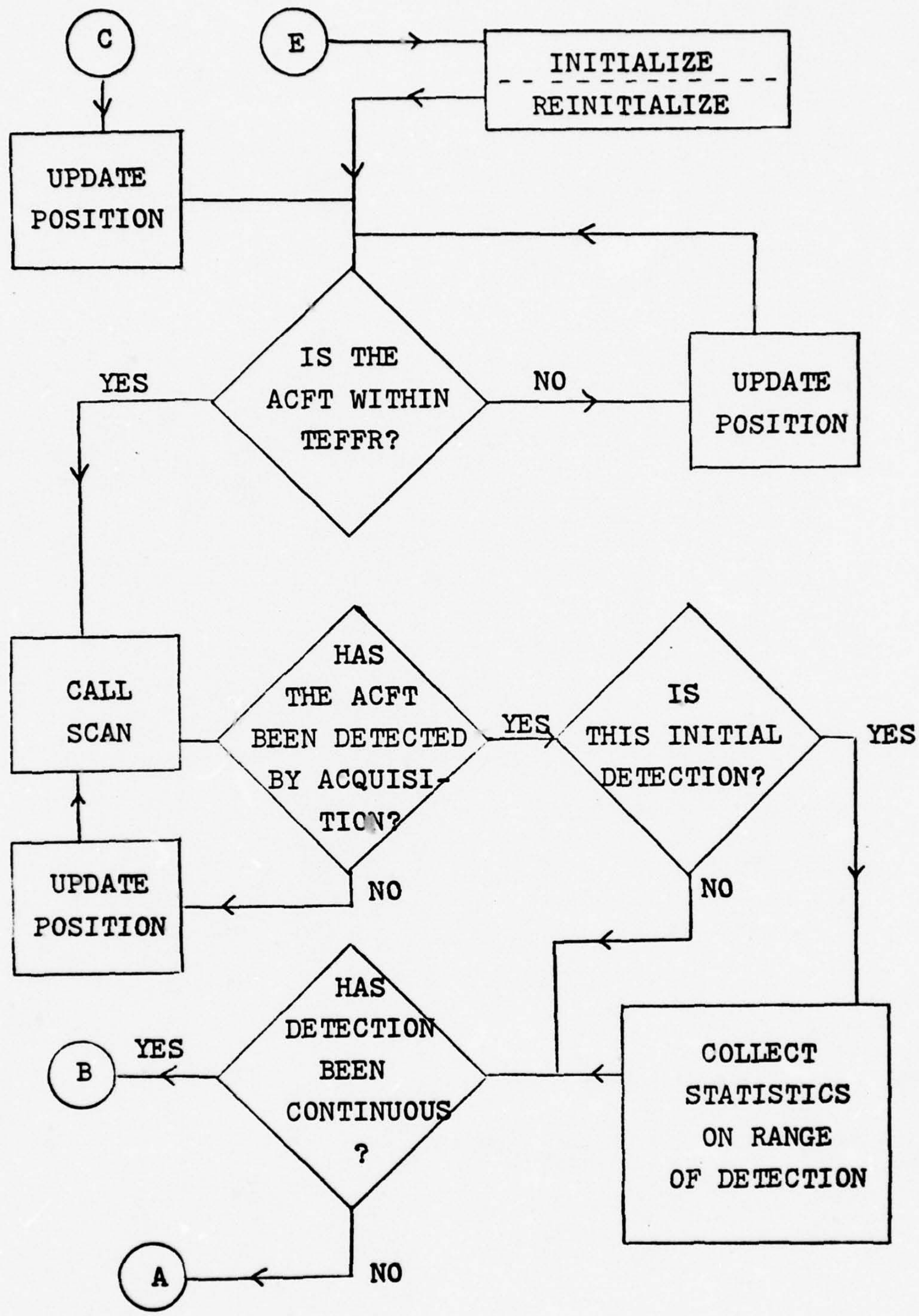


Fig. 8. A General Flowchart of FB4

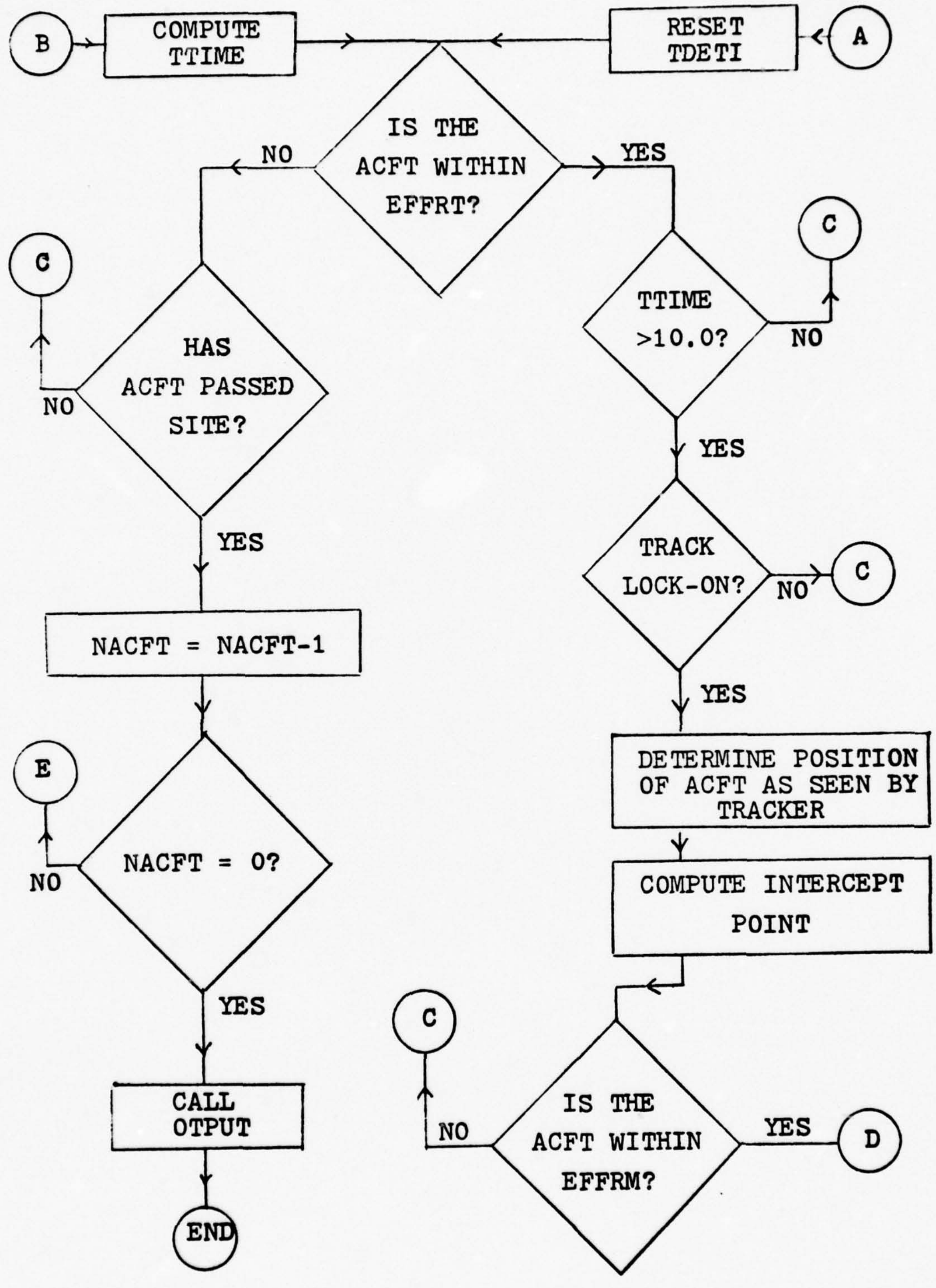


Fig. 8. A General Flowchart of FB4 (Continued)

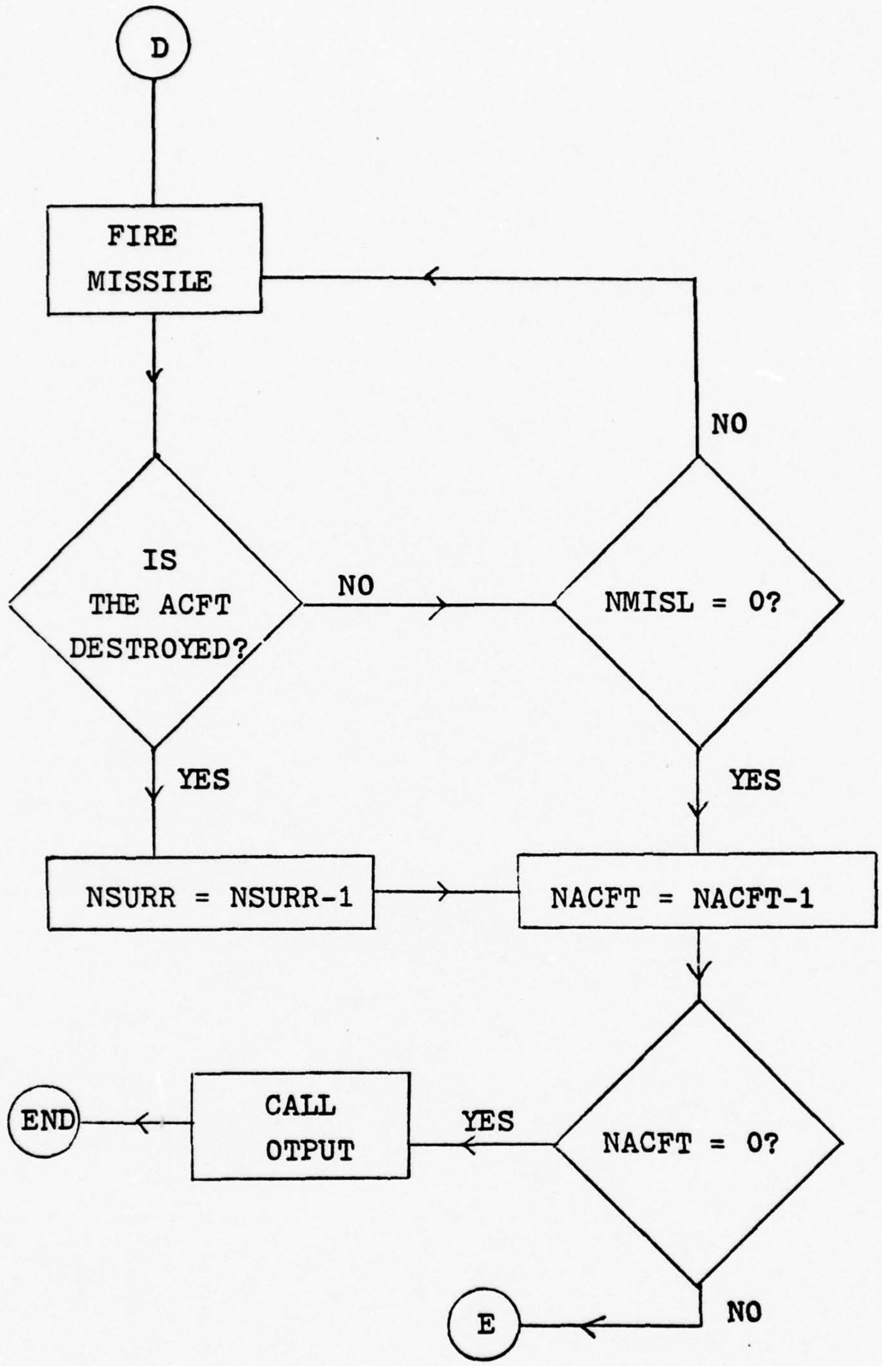


Fig. 8. A General Flowchart of FB4 (Concluded)

FB1, FB2, and FB3. It updates the aircraft position and the aircraft range SS(1), the only state variable. STATE is listed on page 15.

Upon exiting from STATE, GASP calls SCOND, which determines if any state conditions have been met. The statements in SCOND are as follows:

```
LFLAG(1)=KROSS(1,0,0.0,TEFFR,+1,200.0)
LFLAG(2)=KROSS(1,0,0.0,TEFFR,-1,200.0)
LFLAG(3)=KROSS(1,0,0.0,EFFRT,-1,50.0)
LFLAG(4)=KROSS(1,0,0.0,MINEFR,-1,50.0)
```

LFLAG(1) and LFLAG(2) are used the same way as in previous programs. They check to see if the aircraft is withdrawing or penetrating, respectively. LFLAG(3) and LFLAG(4) reflect the addition of two new state conditions. When the aircraft comes within effective range of the tracking device, LFLAG(3) will be set to a value of -1 to denote the crossing. When LFLAG(4) is set to -1, the aircraft has passed within minimum effective range of the missile and cannot be fired on. It is assumed in this scenario that missiles will be fired at incoming aircraft only.

The program progresses with GASP constantly updating TNOW until one of the events in SCOND occurs. A call to EVNTS is then made with the appropriate IX value. The first call to EVNTS must be a state-event since both time-events have ATRIB(1) read in as 1.E20. The statements in EVNTS are as follows:

```
      GO TO (101,102,103),IX
  102 CALL SCAN
```

```
      GO TO 110
  103 CALL SCANT
      GO TO 110
  101 CONTINUE
      IF (LFLAG(2).EQ.-1) CALL AIRNG
      IF (LFLAG(1).EQ.+1) CALL AORNG
      IF (LFLAG(3).EQ.-1) CALL AIRNGT
      IF (LFLAG(4).EQ.-1) CALL OTPUT
```

The computed GO TO statement separates time-events from state-events. In FB4, the state-event code is 1. If IX=1, then each flag is checked and the appropriate subroutine is called. Each of the subroutines will be discussed in the following paragraphs.

The AIRNG subroutine is the same as in FB3 except for the print statements. A listing of this subroutine follows:

```
      ATRIB(1)=TNOW
      ATRIB(2)=2.0
      CALL FILEM(1)
```

The purpose of this subroutine is to initiate the scanning of the acquisition radar. This is a time-event, SCAN, and it is started by setting the start time to TNOW. ATRIB(2) is used to identify which time-event is being changed. FILEM does the storage and retrieval job.

After return to EVNTS from AIRNG, EVNTS gives the program back to GASP. GASP notes that ATRIB(1) of time-event 2 is equal to TNOW. SCAN is called immediately. A listing of this subroutine follows:

```
      PRBDET=AMIN1(HIALT/SS(1),1.)
      X=DRAND(1)
      IF (X-PRBDET)101,101,102
  101 CALL DETECT
      GO TO 103
```

```
102 KFLAG=1
103 ATRIB(1)=TNOW+SCANR
    ATRIB(2)=2.0
    CALL FILEM(1)
110 RETURN
```

The first statement determines the probability of detecting the aircraft, PRBDET. Next, a random number X is called from DRAND and compared with PRBDET. If X is greater than PRBDET, detection does not occur. The flag KFLAG is then set to 1. This means if the aircraft is detected and then lost, the fact that detection has not been continuous will be stored in KFLAG. The last statements reassign a new time for SCAN to begin again, depending on the scan rate of the radar, SCANR.

If X is less than PRBDET, then the aircraft has been detected and DETECT is called. A listing of this subroutine appears below:

```
    IF (MFLAG.EQ.0) GO TO 800
    CALL HISTO (SS(1),1)
    CALL COLCT (SS(1),1)
    MFLAG=0
    TDETI=TNOW
800 IF (KFLAG.EQ.1) GO TO 900
    TTIME=TNOW-TDETI
    GO TO 110
900 TDETI=TNOW
    KFLAG=0
110 RETURN
```

The first statement uses MFLAG to determine if this is the first time the aircraft has been detected. If yes, then statistics are collected on range of detection. MFLAG is then changed so that statistics on range of detection cannot be collected on this aircraft again. Also, the initial

time of detection, TDETI, is set.

If detection was not made during the previous scan, the initial time of detection is reset. KFLAG is used to determine if detection did not occur and TDETI is reset only if KFLAG=1. If TDETI is reset, KFLAG is also reset. If detection has been continuous, the total time is computed and stored in TTIME. This process of scanning and detecting continues until another state-event or time-event occurs. In FB4, this happens when the aircraft crosses EFFRT and comes within range of the tracking device. AIRNGT is then called by EVNTS.

The AIRNGT subroutine serves the same purpose for the tracking device as AIRNG does for the acquisition radar. A listing of this subroutine appears below:

```
      ATRIB(1)=TNOW
      ATRIB(2)=3.0
      CALL FILEM(1)
```

The time of occurrence of time-event 3, which is SCANT, is set to TNOW. Upon return to GASP, SCANT is called immediately.

SCANT is to the tracking device what SCAN is to the acquisition radar. It scans the aircraft at periodic intervals and determines if the aircraft is being tracked by the tracking device. The following is a listing of SCANT:

```
      IF (TTIME-10.0) 100,100,101
  100 PRBTRK=0.0
      GO TO 102
  101 PRBTRK=AMIN1(HIALT/SS(1),1.)
      Y=RNORM(1,1)
```

```
102 IF (Y-PRBTRK) 103,103,104
103 IF (JFLAG.EQ.0) GO TO 105
    JFLAG=0
    CALL COLCT (SS(1),2)
    CALL HISTO (SS(1),2)
105 CALL TRACK
104 ATRIB(1)=TNOW+SCANRT
    ATRIB(2)=3.0
    CALL FILEM(1)
110 RETURN
```

The first statement determines if the aircraft has been detected long enough for the tracking device to get the information necessary for accurate positioning to find the aircraft. An arbitrary time of 10.0s has been used. If TTIME is not greater than 10.0s, "lock-on" is not allowed. If TTIME is greater than 10.0s, then the probability of tracking, PRBTRK, is computed in the same manner as PRBDET in SCAN. A random number Y is then pulled from DRAND and if it is greater than PRBTRK, the aircraft is not detected by the tracking device. When this occurs, the time of next occurrence of SCANT is set to TNOW+SCANRT, where SCANRT is the scanning rate of the tracking device.

If Y is less than or equal to PRBTRK, the tracking device "locks-on" to the aircraft. The flag JFLAG is then used to determine if this is initial "lock-on". If yes, then statistics are collected and JFLAG set so that they cannot be collected again on this aircraft. Then subroutine TRACK is called. If statistics have already been collected, TRACK is called immediately.

TRACK is used to determine where the aircraft is and to compute an intercept point at which to fire the missile.

A listing of TRACK follows:

```
      D=RNORM(2,2)
      E=RNORM(3,3)
      F=RNORM(4,4)
      SST=SS(1)+D
      THETA=ATAN(POSAZ/POSAY)+E
      PHE=ATAN(POSAY/POSAX)+F
      BARK=((POSAY-POSTY)/(POSAZ-POSTZ))**2.0
      BITE=BARK*XMSPED**2.0
      DOG1=BITE+XMSPED**2.0
      DOG2=-BITE+RVEL**2.0
      DOG3=4.0*(RVEL*XMSPED)**2.0
      DOG4=DOG3**.5
      ANGLE=ACOS((-DOG4+(DOG3-4*DOG1*DOG2)**.5)/(2*DOG1))
      MFLTT=(POSAZ-POSTZ)/(-RVEL*SIN(ANGLE))
      POSAX=POSAXI+ASPEDX*(TNOW+MFLTT)
      POSAY=POSAYI+ASPEDY*(TNOW+MFLTT)
      POSAZ=POSAZI+ASPEDZ*(TNOW+MFLTT)
      SST=(POSAX**2+POSAY**2+POSAZ**2)**.5+D
      PHE=ATAN(POSAY/POSAX)+F
      THETA=ATAN(POSAZ/POSAY)+E
      POSMX=SST*COS(PHE)
      POSMY=SST*COS(THETA)
      POSMZ=SST*SIN(THETA)
      IF (SS(1)-EFFRM)101,101,110
  101 CALL FIREM
  110 RETURN
```

D, E, and F are random numbers pulled from RNORM. They are then added to SST, THETA, and PHE, respectively, to simulate errors in the tracking device. The range, elevation, and azimuth of the aircraft as seen by the tracker are then used along with aircraft and missile speed to determine an intercept point. The formulas and diagrams used to compute this intercept are listed in Appendix B. The quadratic equation

$$x = \frac{-b \pm (b^2 - 4ac)^{1/2}}{2a}$$

is used to make the final calculation. The BARK, BITE, and DOG statements are all various pieces of this equation. The

final answer is the time of flight of the missile to the intercept point, or MFLTT.

Once MFLTT is known, the computed aircraft position is updated by the appropriate time. A new range, elevation, and azimuth are then computed and used to determine a position at which to fire the missile. These coordinates are POSMX, POSMY, and POSMZ. The missile, when fired, is assumed to make a perfect launch and flight to these coordinates and detonate.

To determine if a missile is to be fired, the range to the aircraft is compared with the missile's effective range. If the aircraft is not in range, the program is returned to SCANT where the process continues. When the aircraft is in range, TRACK calls FIREM.

The FIREM subroutine is used to fire missiles at the aircraft. A listing of FIREM follows:

```
      IF (NMISL.GT.0) GO TO 108
      GO TO 111
  108 IF (TNOW.GE.DELAY) GO TO 109
      GO TO 110
  109 XMISS=((POSMY-POSAY)**2.0+(POSMX-POSAX)**2.0+
            (POSMZ-POSAZ)**2.0)**
     1.5
      DELAY=TNOW+5.0
      NMISL=NMISL-1
      CALL COLCT(SS(1),3)
      CALL HISTO(SS(1),3)
      IF (XMISS-66.0)101,110,110
  101 NSURR=NSURR-1
  111 CALL OTPUT
  110 RETURN
```

A check is first made to determine if the missiles at the site have all been fired. If yes, then an immediate call

is made to OTPUT. If no, then the time since the last missile was fired is computed to determine if another missile is ready. The time DELAY is used to prepare a missile for firing after a missile is fired. If another missile is not ready, a return to TRACK is made.

If a missile is ready for firing, it is fired by computing the miss distance XMISS. Statistics are then collected on the range at which firing was accomplished. Also, the number of missiles is reduced by 1 and the time delay between missiles is set. To determine if the aircraft has been shot down, the distance missed is compared with 66m. The aircraft is considered shot down if XMISS is less than 66m. If the aircraft is not shot down, the program returns to TRACK. If the aircraft is shot down, then the number of survivors is reduced by 1 and OTPUT is called.

A listing of subroutine OTPUT appears below:

```
    NNSURR=NACFTI-NSURR
    NACFT=NACFT-1
    IF (NACFT.EQ.0) GO TO 200
    CALL INTLC
    GO TO 110
200 PRINT (6,160) NSURR,NNSURR
160 FORMAT (" THE NUMBER OF SURVIVING ACFT IS ",I5,/,
         " THE NUMBER SHOT
  1 DOWN IS ",I5)
700 MSTOP=-1
110 RETURN
```

This subroutine first computes the number of aircraft shot down, NNSURR. The number of aircraft is reduced by 1 and then OTPUT determines if any aircraft remain to fly through the threat area. If yes, INTLC is called and the simulation

repeated. If no, the number of survivors and number of aircraft shot down are printed and the simulation ended by setting MSTOP to a negative value.

If the aircraft passes through the threat area without being fired on or if the threat does not fire all of its missiles, then subroutine AORNG is called when the aircraft crosses MINEFR. A listing of this subroutine follows:

```
          ATRIB(1)=1.E20
          ATRIB(2)=2.0
          CALL FILEM(1)
          ATRIB(1)=1.E20
          ATRIB(2)=3.0
          CALL FILEM(1)
          CALL OTPUT
      110 RETURN
```

This subroutine stops SCAN and SCANT from searching for the aircraft by setting their time of next occurrence far into the future. A call is then made to OTPUT.

This is the last of the Fly By programs. The results of FB4 are discussed in Chapter V. and listed in Appendix A.

IV. Optical Engagement

SAM Operation

Each missile system has an engagement envelope. This envelope, ideally, encompasses the area around the site where the missile could be used to kill an aircraft. A general picture of this envelope is shown in Fig. 9 below.

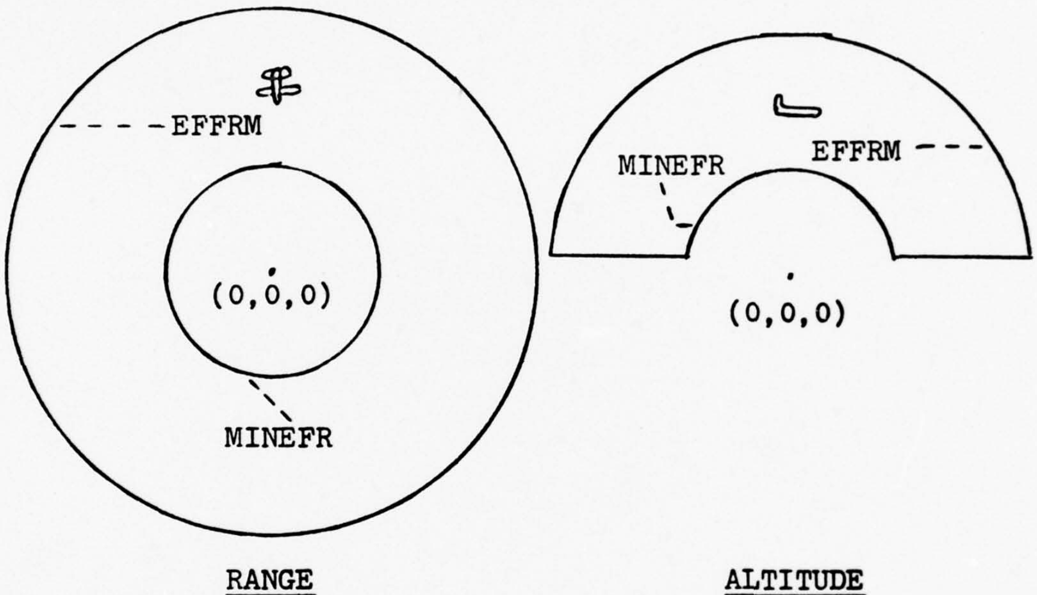


Fig. 9. Ideal Missile Engagement Envelope

The missile's characteristics, combined with those of the tracking and guidance device, determine its maximum slant range, minimum slant range, and maximum and minimum altitude of effectiveness. These parameters give us the "ideal" missile envelope. But there is more to the problem.

A slow missile would not catch an aircraft going away.

Also, the tracking device requires a certain amount of time to determine a firing position, even if the aircraft is already within range. Infra-red, or heat-seeking, missiles are less effective when used against on-coming aircraft. These parameters and their limitations lead to an operational envelope. The missile is fired only when there is a reasonable chance of success. A general picture of what an operational envelope might look like is shown in Fig. 10 below.

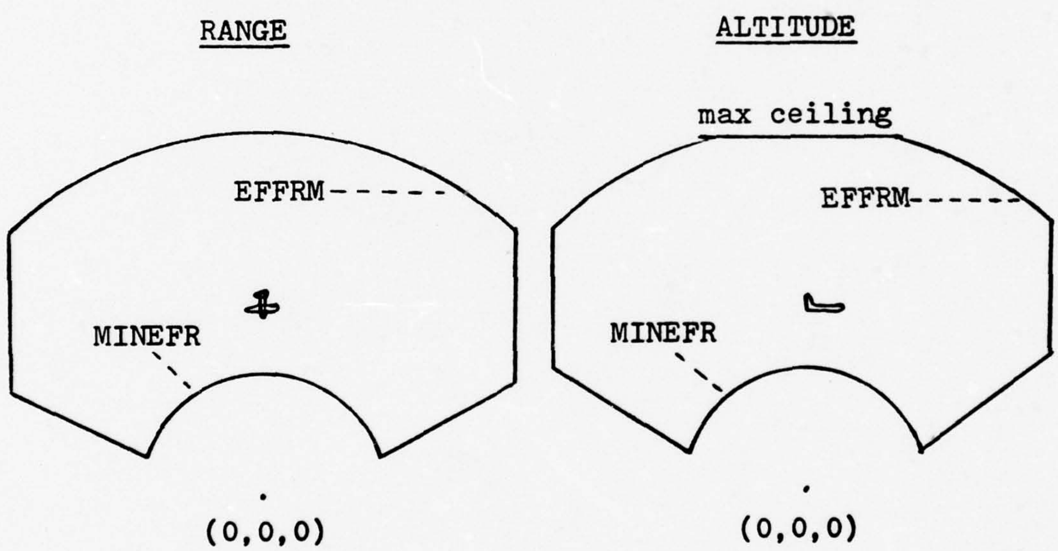


Fig. 10. Operational Engagement Envelope

Most of the parameters described above have been used in the Fly By programs. Some of these are missile speed, XMSPED, its minimum and maximum effective ranges, MINERF and EFFRM, and the effective range of the tracking device,

EFFRT. The numbers used to denote these parameters in the Fly By programs are not peculiar to any one system. To keep the report unclassified, they were simply selected arbitrarily but kept reasonable. The program is flexible so that each of these parameters can be changed to reflect specific systems in the future. It would also be rather easy to add other parameters necessary to make the programs more realistic.

One other device of interest in this engagement is the optical device being used by the SAM guidance or tracking system. Data on exactly what happens to optical systems when hit by various known or proposed countermeasures devices is currently being sought. Some experiments are already being conducted and others are in the planning stages. These optical devices have not been incorporated into the Fly By programs. However, when the data has been obtained and the pertinent parameters determined, Fly By 4 will require few or no changes to incorporate the device as the tracker in the SCANT and TRACK subroutines. What data that is obtainable is being gathered at the AFAL library, where it will be available for future use.

Other parameters of the tracking device need to be incorporated to make the program realistic. For an optical device, the contrast of the aircraft plays an important role. The characteristics of the atmosphere will also have to be taken into account. The probability of lock-on must be made to reflect these parameters.

OCM Parameters

A SAM will kill if it reaches a point in the air where the warhead is within lethal range of an aircraft and is then detonated. This kill distance varies with the warhead type. The essence of a countermeasure device is to degrade the tracking device to the point that it cannot guide a missile within lethal range of the aircraft. This could occur after a missile has been launched, since most missiles are guided to the target. For AAA systems, this is not the case. Once the shell leaves the gun, it does not matter that the tracker cannot see you, at least not as far as that shell is concerned. So in the case of optically guided AAA, you must stop the tracker from ever knowing your position accurately enough for the AAA to become effective. Thus, the purpose of the countermeasures device is to introduce errors into the tracking system of the threat and to thus degrade the system to such a point that its effectiveness is greatly reduced.

No data was available on the devices under current study to be used as optical countermeasures systems. The parameters of these devices are known, but are sensitive and cannot be discussed in this report.

Fly By 5

The next step in developing the optical analysis is the Fly By 5 program. This program will incorporate new subroutines and changes to old ones to reflect a realistic optical engagement. A discussion of changes will be first.

In the Fly By programs in this report, the detection and tracking probabilities are generated using the range of the aircraft and the number HIALT. This number incorporates all the parameters not specifically mentioned, such as aircraft cross-section, contrast, power of the radar or optical device, and field of view of the tracker, into one number which is then used to determine the probabilities. This is too simplified for a realistic engagement. The HIALT number must be calculated using the above parameters and any others which might apply. There are several computer programs in the RF regime which could be used as guides in changing the INTLC subroutine to reflect the new HIALT. One of these is the P001 AAA program used at AFAL. It was used extensively to obtain an overall view of the engagement process described in this report (Ref 2). Another approach would be to write a new subroutine called PROBD to determine the value of the number HIALT. Either method would give a more realistic tracking and detection model.

Other changes would have to be made in the FIREM subroutine to reflect the possible use of different detonating devices. A missile being detonated by an observer on the ground or at a computer calculated time of closest approach would have a different effect than one with a contact or proximity fuse. Also, some missiles can be fired at aircraft going away. This would have to be incorporated into the FIREM and TRACK subroutines.

To reflect countermeasure degradation of the tracking

system, a new subroutine JAMMER must be written. As envisioned, this subroutine would incorporate the parameters of the OCM devices and deliver as output a tracking degradation number. This number would be used in the TRACK subroutine to determine where the tracker sees the aircraft. All of the parameters of the OCM device would be involved, as well as the atmospheric properties. Input would come from another new subroutine, RECEIV.

RECEIV would model the countermeasures receiver and its ability to detect optical threats. The parameters of the threat, the aircraft, and the atmosphere would be combined to deliver the range, azimuth, and priority of the threat. This data would be sent to JAMMER. A flowchart showing where the two new subroutines would be incorporated into Fly By 4 is shown in Fig. 11 on page 50.

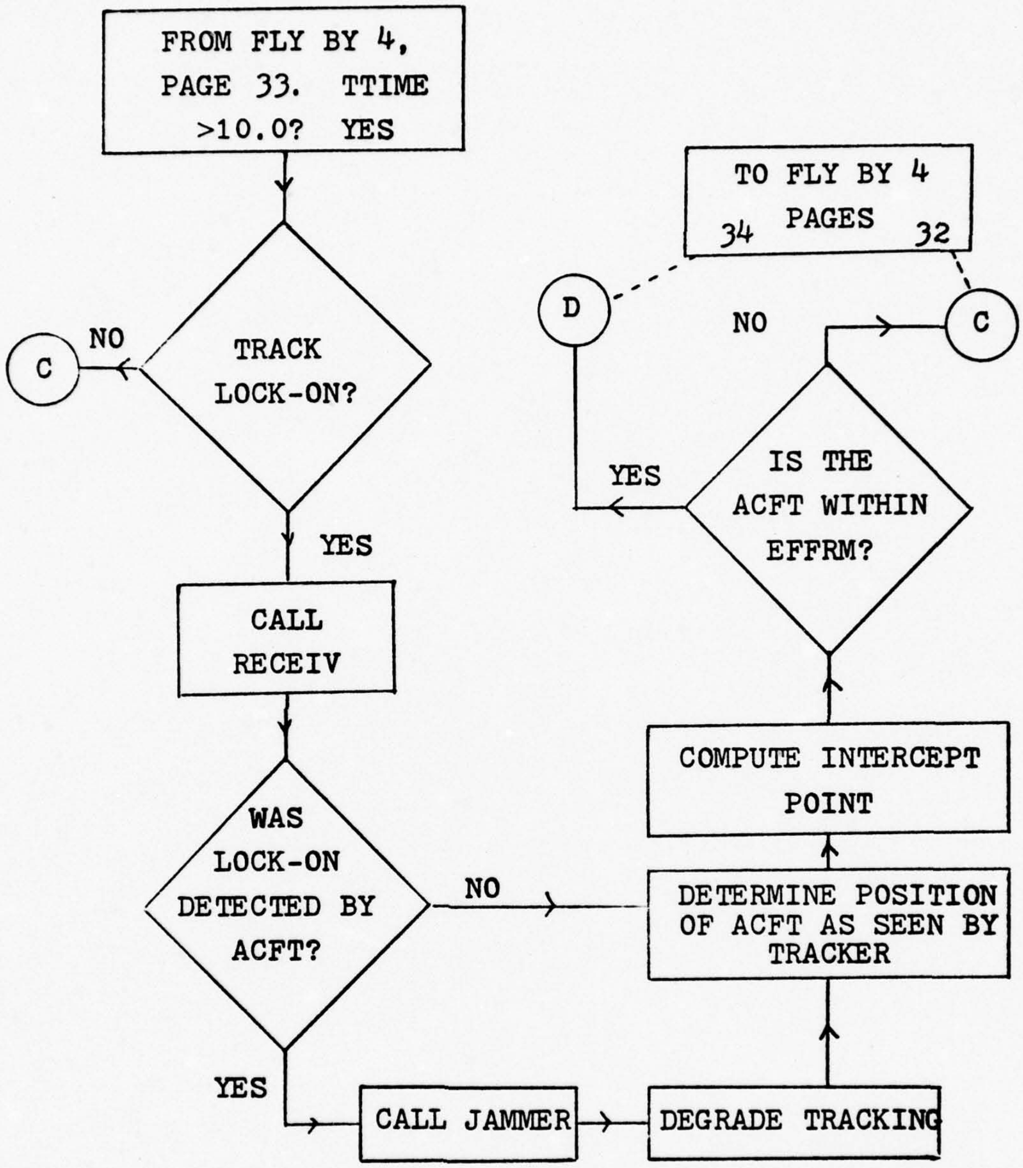


Fig. 11. Flowchart of FB4 Changes for FB5

V. Results

General

Each Fly By program has a different set of data cards. To help keep track of the values used by GASP, each program prints out a simulation project number followed by all the values read in on the GASP data cards. A detailed explanation of these values can be found in Ref 1, Chapter 3.

Another GASP printout lists the contents of all the files and the contents of the state variable storage area. This is done twice for each program. The headings are GASP FILE STORAGE AREA DUMP and GASP STATE STORAGE AREA DUMP. The value of TNOW at the time of the dump is listed after the title in the printout. A dump is made for values of TNOW at the beginning and end of the simulation.

One other GASP printout occurs. This is the GASP summary report, which lists the project number, date, parameter sets, and the statistics collected on each variable. All of these printouts are listed with the user results in Appendix A.

Fly By 1

Project 1 is the simplest. The aircraft is detected as it crosses TEFFR inbound and outbound. No statistics are collected and only one aircraft is involved. The INTERMEDIATE RESULTS are as follows:

```
TNOW =        6.00
COORDINATES ARE        0.00    8600.00    5000.00
RANGE=     9947.86
```

```
TNOW=            49.25
COORDINATES ARE           0.00   -8700.00    5000.00
RANGE=     10034.44
```

As can be seen, the aircraft crossed TEFFR inbound at time TNOW=6.00s. The actual range was 9947.86m, which is well within the 200m tolerance set in KROSS. As the aircraft left the area, it crossed TEFFR at TNOW=49.25s at a range of 10034.44m, again well within tolerances.

Although the results are rather simplistic, one of the major purposes of Fly By 1 was to become familiar with the GASP executive. Fly By 1 was accomplished with this in mind and succeeded in laying the groundwork for continuing to Fly By 2.

Fly By 2

In Fly By 2, the SCAN and DETECT subroutines were added to make the detection process more realistic. Again, no statistics were collected. The INTERMEDIATE RESULTS are listed below:

```
     THE ACFT IS IN RANGE
TNOW =          6.00
COORDINATES ARE          0.00    8600.00    5000.00
RANGE=     9947.86
     THE ACFT HAS BEEN DETECTED
TNOW            6.00
COORDINATES ARE          0.00    8600.00    5000.00
RANGE=     9947.86
```

The flags about range and detection indicate that the information following concerns time, coordinates, and range of crossing TEFFR and detection by SCAN, respectively. The values used for the different variables caused detection to

occur when the aircraft crossed TEFFR. The information printed in Fly By 1 about aircraft withdrawal does not appear because the simulation ends when the aircraft is detected. If the aircraft was not detected, the AORNG subroutine would print out the aircraft withdrawal information beneath the flag "THE ACFT IS OUT OF RANGE". A complete listing of the Fly By 2 results and printout begins on page 63 in Appendix A.

<u>Fly By 3</u>

This program is the first in which more than one aircraft was used and statistics collected. Use of more than one aircraft does not mean the one-on-one has been abandoned, but that it is being repeated several times. This is reflected throughout the results and printout, which is listed in Appendix A beginning with page 66. The first few lines of the INTERMEDIATE RESULTS are listed below:

```
     THE AIRCRAFT HAS BEEN DETECTED
TNOW =         73.75
COORDINATES ARE        0.00    27250.00    5000.00
RANGE IS  27704.92
     THE AIRCRAFT HAS BEEN DETECTED
TNOW =         15.75
COORDINATES ARE        0.00    38850.00    5000.00
RANGE IS  39170.43
```

All twenty aircraft are detected before passing out of the threat area and the appropriate flag, time, position, and range of each detection are listed. The data above represents two aircraft. In addition, statistics are collected and printed in the summary report. A listing of these

statistics is shown below.

RNG DET	
MEAN	.3691E+05
STD DEV	.3092E+04
SD OF THE MEAN	.6915E+03
CV	.8377E-01
MINIMUM	.2770E+05
MAXIMUM	.3996E+05
OBS	20

The closest an aircraft came to the site before detection occurred was 27250.00m. The mean range of detection was 36910.0m, with a standard deviation of 691.5m

The last data printed out by Fly By 3 is a histogram of the range of detection. It is shown in Appendix A on page 72. This histogram shows relative and cumulative frequency of observation of the values between the upper and lower limits of each cell. The C indicators are for the cumulative graph, while the * indicators tell what percentage of the total observations fell within each range of values.

Fly By 4

In Fly By 4, the flags for aircraft detection, penetration, and withdrawal were dropped. Therefore, the INTERMEDIATE RESULTS only contains information on aircraft survivability. These results are listed below:

THE NUMBER OF SURVIVING ACFT IS	6
THE NUMBER SHOT DOWN IS	14

Data has also been collected on three variables. The

statistics are calculated and then printed out in tabular form. They are listed below:

	RNG DET	RNG TRK	RNG FIR
MEAN	.1422E+06	.5024E+05	.3952E+05
STD DEV	.1364E+04	.2948E+04	.5463E+03
SD OF MEAN	.3051E+03	.6592E+03	.9510E+02
CV	.9593E-02	.5868E-01	.1382E-01
MINIMUM	.1379E+06	0.0	0.0
MAXIMUM	.1432E+06	.5380E+05	.3995E+05
OBS	20	20	33

The printout is completed with the histograms of the three variables. These are listed in Appendix B, starting on page . As would be expected, a large number of the aircraft are detected as soon as they enter TEFFR. the RNG TRK histogram shows that the tracker "locked-on" to all but one aircraft as they came within range. And once "locked-on", the threat fired a missile at each aircraft as it crossed EFFRM. Seven aircraft were destroyed by the missiles on the first shot, while only six survived the second round.

Summary

With Fly By 4, a point has been reached at which a true optical engagement can now be realistically programmed. The program scans, detects, tracks, and fires at the aircraft with parameters that are set by the user. With this flexibility and the addition of subroutines representing the receiver and jammer on the aircraft, Fly By 5 will give some realistic data on the effectiveness of optics. The limitations of the program have been noted, but the flexibility allows the program to easily model any situation.

VI. Recommendations

The ultimate goal of this project is to build a computer program to analyze a one-on-one engagement in the optical regime. As stated before, certain additions to the Fly By 4 program must be made to reach this goal. Data on the receiver and countermeasures devices must be collected and analyzed to determine what parameters need to be included in the JAMMER and RECEIV subroutines. This means a large amount of data must be collected. One possible way would be to propose an AFIT thesis to research and collect data on optical receivers and jammers and put it into usable form. A tabulation of these devices, both existing and proposed, would be invaluable to individuals in the AFAL who will continue this project. Many of the documents necessary to complete such an analysis have been ordered by the AFAL library but were not available when this report was written. It is felt that collection and compilation of data is essential to the successful completion of the one-on-one project.

Another area requires the collection of large amounts of data. The characteristics of the threat optical devices need to be researched and cataloged. Although many sources of this data exist, only a few of them are at the AFAL library. Those ordered for this report were not available at its completion. However, they could not have been included if this report was to remain unclassified. The data exist and must be collected and tabulated.

One large grey area which was discovered during this

report concerns the effect of optical countermeasures devices on optical threat devices. Several experiments have been conducted or are being conducted at this time concerning these effects. Information available indicates wide variances in the results. The pertinent questions include the following:

1. What effect does the countermeasures device have on the optics and its ability to see the aircraft?

2. How much error must be introduced to give reasonable chance of aircraft survival?

3. How much bloom time is required to introduce a specific error?

4. Does a laser device destroy a video tube or just cause it to bloom?

5. What power level is required for destruction?

6. What power level is required for blooming?

7. How long does blooming last at different power levels?

These and other questions must be answered and put into a form which can be included in the parameters of Fly By 5. An AFIT thesis on the effects of a laser hitting a TV video tube would go a long way toward answering these questions and would give AFAL a key on which to evaluate other data. This project will be proposed to the current AFIT physics class.

Bibliography

1. Pritsker, Alan B. The GASP IV Simulation Language. New York: John Wiley & Sons, 1974.

2. Severson, J. and T. McMurchie. Antiaircraft Artillery Simulation Computer Program-AFATL Program P001. Vol. II: Analyst Manual. Eglin AFB, Florida: Air Force Armament Laboratory, 1973.

Appendix A

Printouts of the Fly By Programs

Information marked by * is GASP generated. A detailed explanation can be found in Ref. 1.

```
*                  SIMULATION PROJECT NUMBER  1  BY  PENICK

                   DATE  9/  16/  77      RUN NUMBER   1  of    1
                   LLSUP=000000000000000  GASP IV VERSION 18MAY74

NNCLT=    0  NNSTA=    0  NNHIS=    0  NNPRM=    0  NNPLT=    0  NNSTR=    1  NNTRY=  90
NNATR=    1  NNFIL=    2  NNSET=  300  NNEQD=    0  NNEQS=    1  NFLAG=    2

KKRNK= (  1)    1

IINN = (  1)    1

IIEVT=    1  LLERR=   -0  AAERR=        .1000E-02    RRERR=        .1000E-02
DTMIN=     .2000E-02      DTMAX=        .2500E+00    DTSAV=        .2500E+00

MSTOP=    0  JJCLR=    0  JJBEG=    1  IICRD=   -0  TTBEG=    0.          TTFIN=   -0.
JJFIL=    0
IISED=   -0


*                **GASP FILE STORAGE AREA DUMP AT TIME     0.  **

               MAXIMUM NUMBER OF ENTRIES IN FILE STORAGE AREA = 90

                      PRINTOUT OF FILE NUMBER    1
                         TNOW =  0.
                         QQTIM=  0.

                         THE FILE IS EMPTY

                      PRINTOUT OF FILE NUMBER    2
                         TNOW =  0.
                         QQTIM=  0.

                         THE FILE IS EMPTY
```

```
*              **GASP STATE STORAGE AREA DUMP AT TIME    0.   **

                          (I)          SS(I)            DD(I)
                           1          .1208E+05         0.

                             **INTERMEDIATE RESULTS**

TNOW =               6.00
COORDINATES ARE                 0.00          8600.00        5000.0
RANGE=            9947.86
TNOW =              49.25
COORDINATES ARE                 0.00         -8700.00        5000.0
RANGE=           10034.44


*                            **GASP SUMMARY REPORT**

               SIMULATION PROJECT NUMBER  1  BY  PENICK

               DATE  9/  16/  77       RUN NUMBER   1 OF    1

               CURRENT TIME       .4925E+02

*              **GASP FILE STORAGE AREA DUMP AT TIME    .4925E+02**

               MAXIMUM NUMBER OF ENTRIES IN FILE STORAGE AREA = 90

                         PRINTOUT OF FILE NUMBER    1
                           TNOW =     .4925E+02
                           QQTIM=  0.

                    TIME PERIOD FOR STATISTICS  .4925E+02
                    AVERAGE NUMBER IN FILE           0.0000
```

```
STANDARD DEVIATION              0.0000
MAXIMUM NUMBER IN FILE          0

             THE FILE IS EMPTY


        PRINTOUT OF FILE NUMBER    2
             TNOW =    .4925E+02
             QQTIM=   0.

TIME PERIOD FOR STATISTICS  .4925E+02
AVERAGE NUMBER IN FILE          0.0000
STANDARD DEVIATION              0.0000
MAXIMUM NUMBER IN FILE          0

             THE FILE IS EMPTY


*        **GASP STATE STORAGE AREA DUMP AT TIME    .4925E+02**

             (I)          SS(I)            DD(I)
              1          .1003E+05         0.
```

```
*                         SIMULATION PROJECT NUMBER  2  BY  PENICK

                          DATA  9/ 16/ 77         RUN NUMBER   1  OF    1
                          LLSUP=000000000000000   GASP IV VERSION 18MAY74

NNCLT=     0  NNSTA=     0  NNHIS=     0  NNPRM=     0  NNPLT=     0  NNSTR=     2  NNTRY=  90
NNATR=     2  NNFIL=     2  NNSET=   400  NNEQD=     0  NNEQS=     1  NFLAG=     2

KKRNK= (  1)    1

IINN = (  1)    1

IIEVT=     1  LLERR=    -0  AAERR=         .1000E-02    RRERR=         .1000E-02
DTMIN=      .2500E-02       DTMAX=         .2500E+00    DTSAV=         .2500E+00

MSTOP=     0  JJCLR=     1  JJBEG=     1  IICRD=    -0  TTBEG=      0.          TTFIN=    -0.
JJFIL=     1
IISED= 43295         78163


*                        **GASP FILE STORAGE AREA DUMP AT TIME     0.    **

                     MAXIMUM NUMBER OF ENTRIES IN FILE STORAGE AREA =  0

                               PRINTOUT OF FILE NUMBER    1
                                  TNOW =  0.
                                  QQTIM=  0.

                                  THE FILE IS EMPTY

                               PRINTOUT OF FILE NUMBER    2
                                  TNOW =  0.
                                  QQTIM=  0.

                                  THE FILE IS EMPTY
```

```
*                **GASP STATE STORAGE AREA DUMP AT TIME     0.    **

                          (I)          SS(I)           DD(I)
                           1           .1208E+05       0.

                          **INTERMEDIATE RESULTS**

  THE ACFT IS IN RANGE
TNOW =            6.00
COORDINATES ARE            0.00          8600.0         5000.0
RANGE=          9947.86
  THE ACFT HAS BEEN DETECTED
TNOW =            6.00
COORDINATES ARE            0.00          8600.00        5000.0
RANGE=          9947.86


*                          **GASP SUMMARY REPORT**

                 SIMULATION PROJECT NUMBER  2  BY  PENICK

                 DATE  9/  16/  77      RUN NUMBER   1  OF    1

*                **GASP FILE STORAGE AREA DUMP AT TIME    .6000E+01**

                MAXIMUM NUMBER OF ENTRIES IN FILE STORAGE AREA =  1

                          PRINTOUT OF FILE NUMBER   1
                             TNOW =    .6000E+01
                             QQTIM=    .6000E+01

                    TIME PERIOD FOR STATISTICS   .6000E+01
                    AVERAGE NUMBER IN FILE          0.0000
```

```
            STANDARD DEVIATION             0.0000
            MAXIMUM NUMBER IN FILE         1

                      FILE CONTENTS
ENTRY   1  =   .1600E+02    .2000E+01


                 PRINTOUT OF FILE NUMBER  2
                    TNOW =    .6000E+01
                    QQTIM=   0.

            TIME PERIOD FOR STATISTICS  .6000E+01
            AVERAGE NUMBER IN FILE         0.0000
            STANDARD DEVIATION             0.0000
            MAXIMUM NUMBER IN FILE         0

                    THE FILE IS EMPTY


*           **GASP STATE STORAGE AREA DUMP AT TIME    .6000E+01

                 (I)        SS(I)           DD(I)
                  1         .9948E+04       0.
```

```
*                    SIMULATION PROJECT NUMBER  3  BY  PENICK

                     DATE  9/  16/  77        RUN NUMBER   1  OF    1
                     LLSUP=000000000000000    GASP IV VERSION 18MAY74

NNCLT=    1  NNSTA=    0  NNHIS=    1  NNPRM=    0  NNPLT=    0  NNSTR=    1  NNTRY=  80
NNATR=    2  NNFIL=    1  NNSET=  500  NNEQD=    0  NNEQS=    1  NFLAG=    2

COLCT NO. 1  LLABC=RNG DET

HISTO NO. 1  LLABH=RNG DET               NNCEL=   20  HHLOW=  .3550E+05   HHWID= .2500E+03

KKRNK= (  1)

IINN = (  1)

IIEVT=    1  LLERR=   -0  AAERR=        .1000E-02    RRERR=        .1000E-02
DTMIN=     .2500E+00      DTMAX=        .2500E+00    DTSAV=        .2500E+00

MSTOP=    0  JJCLR=    0  JJBEG=    1  IICRD=   11  TTBEG=    0.          TTFIN=  -0.
JJFIL=    1
IISED= 43921


*                   **GASP FILE STORAGE AREA DUMP AT TIME    0.   **

                  MAXIMUM NUMBER OF ENTRIES IN FILE STORAGE AREA =  1

                        PRINTOUT OF FILE NUMBER   1
                          TNOW =  0.
                          QQTIM=  0.

                          FILE CONTENTS
ENTRY   1  =    .1000E+201    .2000E+01
```

```
*                **GASP STATE STORAGE AREA DUMP AT TIME    0.  **

                          (I)          SS(I)            DD(I)
                           1          .4230E+05         0.


                         **INTERMEDIATE RESULTS**

  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              73.75
COORDINATES ARE                 0.00        27250.00        5000.00
RANGE IS         27704.92
  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              15.75
COORDINATES ARE                 0.00        38850.00        5000.00
RANGE IS         39170.43
  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              29.75
COORDINATES ARE                 0.00        36050.00        5000.00
RANGE IS         36395.09
  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              13.75
COORDINATES ARE                 0.00        39250.00        5000.00
RANGE IS         39567.19
  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              11.75
COORDINATES ARE                 0.00        39650.00        5000.00
RANGE IS         39964.02
  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              19.75
COORDINATES ARE                 0.00        38050.00        5000.00
RANGE IS         38377.11
  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              39.75
COORDINATES ARE                 0.00        34050.00        5000.00
```

```
RANGE IS          34415.15
  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              31.75
COORDINATES ARE                0.00        35650.00       5000.00
RANGE IS          35998.92
  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              29.75
COORDINATES ARE                0.00        36050.00       5000.00
RANGE IS          36395.09
  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              21.75
COORDINATES ARE                0.00        37650.00       5000.00
RANGE IS          37980.55
  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              17.75
COORDINATES ARE                0.00        38450.00       5000.00
RANGE IS          38773.73
  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              19.75
COORDINATES ARE                0.00        38050.00       5000.00
RANGE IS          38377.11
  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              13.75
COORDINATES ARE                0.00        39250.00       5000.00
RANGE IS          39567.19
  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              11.75
COORDINATES ARE                0.00        39650.00       5000.00
RANGE IS          39964.02
  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              13.75
COORDINATES ARE                0.00        39250.00       5000.00
RANGE IS          39567.19
  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              37.75
COORDINATES ARE                0.00        34450.00       5000.00
```

```
RANGE IS          34810.95
  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              23.75
COORDINATES ARE                 0.00       37250.00       5000.00
RANGE IS          37584.07
  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              23.75
COORDINATES ARE                 0.00       37250.00       5000.00
RANGE IS          37584.07
  THE AIRCRAFT HAS BEEN DETECTED
TNOW IS              45.75
COORDINATES ARE                 0.00       32850.00       5000.00
```

*   **GASP SUMMARY REPORT**

SIMULATION PROJECT NUMBER 3 BY PENICK

DATE 9/ 16/ 77 . RUN NUMBER 1 OF 1

CURRENT TIME = .4575E+02

STATISTICS FOR VARIABLES BASED ON OBSERVATIONS

	MEAN	STD DEV	SD OF MEAN	CV	MINIMUM	MAXIMUM	OBS
RNG DET	.3691E+05	.3092E+04	.6915E+03	.8377E-01	.2770E+05	.3996E+05	20

*   **GASP FILE STORAGE AREA DUMP AT TIME .4575E+02**

```
MAXIMUM NUMBER OF ENTRIES IN FILE STORAGE AREA = 21


          PRINTOUT OF FILE NUMBER    1
              TNOW =     .4575E+02
              QQTIM=     .4575E+02

      TIME PERIOD FOR STATISTICS  .4575E+02
      AVERAGE NUMBER IN FILE        15.8634
      STANDARD DEVIATION             8.7377
      MAXIMUM NUMBER IN FILE             21


                      FILE CONTENTS
ENTRY   1  =   .1000E+21    .2000E+01
ENTRY   2  =   .1000E+21    .2000E+01
ENTRY   3  =   .1000E+21    .2000E+01
ENTRY   4  =   .1000E+21    .2000E+01
ENTRY   5  =   .1000E+21    .2000E+01
ENTRY   6  =   .1000E+21    .2000E+01
ENTRY   7  =   .1000E+21    .2000E+01
ENTRY   8  =   .1000E+21    .2000E+01
ENTRY   9  =   .1000E+21    .2000E+01
ENTRY  10  =   .1000E+21    .2000E+01
ENTRY  11  =   .1000E+21    .2000E+01
ENTRY  12  =   .1000E+21    .2000E+01
ENTRY  13  =   .1000E+21    .2000E+01
ENTRY  14  =   .1000E+21    .2000E+01
ENTRY  15  =   .1000E+21    .2000E+01
ENTRY  16  =   .1000E+21    .2000E+01
ENTRY  17  =   .1000E+21    .2000E+01
ENTRY  18  =   .1000E+21    .2000E+01
ENTRY  19  =   .1000E+21    .2000E+01
```

```
ENTRY  20  =   .1000E+21    .2000E+01
ENTRY  21  =   .1000+201    .2000E+01


*              **GASP STATE STORAGE APEA DUMP AT TIME  .4575E+02**

                    (I)          SS(I)          DD(I)
                     1          .3323E+05       0.
```

HISTOGRAM NUMBER 1

RNG DET

```
OBSV   RELA   CUML      UPPER
FREQ   FREQ   FREQ   CELL LIMIT    0         20        40        60        80        100
                                   +    +    +    +    +    +    +    +    +    +    +
   5   .250   .250   .3550E+05     +*************                                   +
   0  0.000   .250   .3575E+05     +            C                                   +
   1   .050   .300   .3600E+05     +**             C                                +
   0  0.000   .300   .3625E+05     +               C                                +
   2   .100   .400   .3650E+05     +*****               C                           +
   0  0.000   .400   .3675E+05     +                    C                           +
   0  0.000   .400   .3700E+05     +                    C                           +
   0  0.000   .400   .3725E+05     +                    C                           +
   0  0.000   .400   .3750E+05     +                    C                           +
   2   .100   .500   .3775E+05     +*****                    C                      +
   1   .050   .550   .3800E+05     +**                          C                   +
   0  0.000   .550   .3825E+05     +                            C                   +
   2   .100   .650   .3850E+05     +*****                            C              +
   0  0.000   .650   .3875E+05     +                                 C              +
   1   .050   .700   .3900E+05     +**                                 C            +
   1   .050   .750   .3925E+05     +**                                   C          +
   0  0.000   .750   .3950E+05     +                                     C          +
   3   .150   .900   .3975E+05     +*******                                    C   +
   2   .100  1.000   .4000E+05     +*****                                           C
   0  0.000  1.000   .4025E+05     +                                                C
   0  0.000  1.000   .4050E+05     +                                                C
   0  0.000  1.000   .4075E+05     +                                                C
 ---                               +    +    +    +    +    +    +    +    +    +    +
  20                               0         20        40        60        80        100
```

```
*                         SIMULATION PROJECT NUMBER  4  BY  PENICK

                          DATE  9/  16/  77       RUN NUMBER   1  OF    1
                          LLSUP=000000000000000   GASP IV VERSION 18MAY74

NNCLT=      3  NNSTA=      0  NNHIS=      3  NNPRM=      4  NNPLT=      5  NNSTR=      5  NNTRY= 100
NNATR=      2  NNFIL=      1  NNSET= 1800  NNEQD=      0  NNEQS=      1  NFLAG=      4

COLCT NO. 1  LLABC=RNG DET
COLCT NO. 2  LLABC=RNG TRK
COLCT NO. 3  LLABC=RNG FIR

HISTO NO. 1  LLABH=RNG DET            NNCEL=    40  HHLOW=   .1050E+06   HHWID= .5000E+04
HISTO NO. 2  LLABH=RNG TRK            NNCEL=    20  HHLOW=   .4050E+05   HHWID= .5000E+03
HISTO NO. 3  LLABH=RNG FIR            NNCEL=    30  HHLOW=   .1450E+05   HHWID= .1000E+04

KKRNK= (   1)

IINN = (   1)

IIEVT=      1  LLERR=     -0  AAERR=          .1000E-02   RRERR=          .1000E-02
DTMIN=        .2500E+00      DTMAX=          .2000E+01   DTSAV=        0.

PARAMETER SET   1 =      .9000E+00      .8000E+00    .1000E+01    .3300E-01
PARAMETER SET   2 =     0.             -.1800E+03    .1800E+03    .6300E+02
PARAMETER SET   3 =     0.             -.9000E-02    .9000E-02    .3000E-02
PARAMETER SET   4 =     0.             -.9000E-02    .9000E-02    .3000E-02

MSTOP=      0  JJCLR=      0  JJBEG=      1  IICRD=     -0  TTBEG=      0. TTFIN=     -0.
JJFIL=      1
IISED= 51245     32698     51475     21986     53285
```

```
*                  **GASP FILE STORAGE AREA DUMP AT TIME     0.        **

                   MAXIMUM NUMBER OF ENTRIES IN FILE STORAGE AREA = 2


                             PRINTOUT OF FILE NUMBER    1
                                TNOW =   0.
                                QQTIM=   0.

                                FILE CONTENTS
ENTRY    1  =    .1000+201     .2000E+01
ENTRY    2  =    .1000+201     .3000E+01


*                  **GASP STATE STORAGE AREA DUMP AT TIME     0.       **

                             (I)           SS(I)            DD(I)
                              1            .4010E+06        0.

                                **INTERMEDIATE RESULTS**

THE NUMBER OF SURVIVING ACFT IS     6
THE NUMBER SHOT DOWN IS            14


*                               **GASP SUMMARY REPORT**

                   SIMULATION PROJECT NUMBER  4  BY  PENICK

                   DATE  9/  16/  77       RUN NUMBER   1  OF    1

                   CURRENT TIME = 0.
```

```
PARAMETER SET   1 =      .9000E+00     .8000E+00     .1000E+01     .3300E-01
PARAMETER SET   2 =     0.            -.1800E+03     .1800E+03     .6300E+02
PARAMETER SET   3 =     0.            -.9000E-02     .9000E-02     .3000E-02
PARAMETER SET   4 =     0.            -.9000E-02     .9000E-02     .3000E-02


                 **STATISTICS FOR VARIABLES BASED ON OBSERVATIONS**
              MEAN        STD DEV    SD OF MEAN       CV       MINIMUM     MAXIMUM     OBS

RNG DET    .1271E+06    .1531E+05   .3423E+04    .1204E+00   .9400E+05 .1428E+06    20
RNG TRK    .3834E+06    .7847E+05   .1755E+05    .2047E+00  0.          .4009E+06    20
RNG FIR    .3952E+05    .5463E+03   .9510E+02    .1382E-01  0.          .3995E+05    33


*                **GASP FILE STORAGE AREA DUMP AT TIME    0.         **

                 MAXIMUM NUMBER OF ENTRIES IN FILE STORAGE AREA = 42


                      PRINTOUT OF FILE NUMBER   1
                        TNOW =   0.
                        QQTIM=    .1633E+04

                     FILE CONTENTS
ENTRY    1  =    .1633E+04    .3000E+01
ENTRY    2  =    .1633E+04    .3000E+01
ENTRY    3  =    .1633E+04    .3000E+01
ENTRY    4  =    .1633E+04    .3000E+01
ENTRY    5  =    .1633E+04    .3000E+01
ENTRY    6  =    .1633E+04    .3000E+01
ENTRY    7  =    .1633E+04    .3000E+01
ENTRY    8  =    .1633E+04    .3000E+01
ENTRY    9  =    .1633E+04    .3000E+01
ENTRY   10  =    .1633E+04    .3000E+01
```

```
ENTRY  11  =   .1633E+04    .3000E+01
ENTRY  12  =   .1633E+04    .3000E+01
ENTRY  13  =   .1633E+04    .3000E+01
ENTRY  14  =   .1633E+04    .3000E+01
ENTRY  15  =   .1633E+04    .3000E+01
ENTRY  16  =   .1633E+04    .3000E+01
ENTRY  17  =   .1633E+04    .3000E+01
ENTRY  18  =   .1633E+04    .3000E+01
ENTRY  19  =   .1633E+04    .3000E+01
ENTRY  20  =   .1634E+04    .2000E+01
ENTRY  21  =   .1634E+04    .2000E+01
ENTRY  22  =   .1634E+04    .2000E+01
ENTRY  23  =   .1634E+04    .2000E+01
ENTRY  24  =   .1634E+04    .2000E+01
ENTRY  25  =   .1634E+04    .2000E+01
ENTRY  26  =   .1634E+04    .2000E+01
ENTRY  27  =   .1634E+04    .2000E+01
ENTRY  28  =   .1634E+04    .2000E+01
ENTRY  29  =   .1634E+04    .2000E+01
ENTRY  30  =   .1634E+04    .2000E+01
ENTRY  31  =   .1634E+04    .2000E+01
ENTRY  32  =   .1634E+04    .2000E+01
ENTRY  33  =   .1634E+04    .2000E+01
ENTRY  34  =   .1634E+04    .2000E+01
ENTRY  35  =   .1634E+04    .2000E+01
ENTRY  36  =   .1634E+04    .2000E+01
ENTRY  37  =   .1634E+04    .2000E+01
ENTRY  38  =   .1634E+04    .2000E+01
ENTRY  39  =   .1634E+04    .2000E+01
ENTRY  40  =   .1634E+04    .2000E+01
ENTRY  41  =   .1000+201    .2000E+01
ENTRY  42  =   .1000+201    .3000E+01

*            **GASP STATE STORAGE AREA DUMP AT TIME   0.    **

                       (I)        SS(I)           DD(I)
                        1         .3880E+05       0.
```

```
                                **HISTOGRAM NUMBER  1**

                                       RNG DET

OBSV  RELA   CUML      UPPER
FREQ  FREQ   FREQ   CELL LIMIT     0         20        40        60        80       100
                                   +    +    +    +    +    +    +    +    +    +    +
  2   .100   .100   .1050E+06      +*****                                            +
  1   .050   .150   .1100E+06      +**    C                                          +
  2   .100   .250   .1150E+06      +*****      C                                     +
  3   .150   .400   .1200E+06      +*******            C                           +
  1   .050   .450   .1250E+06      +**                   C                          +
  0  0.000   .450   .1300E+06      +                      C                          +
  1   .050   .500   .1350E+06      +**                      C                        +
  5   .250   .750   .1400E+06      +************                      C              +
  5   .250  1.000   .1450E+06      +************                                     C
  0  0.000  1.000   .1500E+06      +                                                 C
  0  0.000  1.000   .1550E+06      +                                                 C
  0  0.000  1.000   .1600E+06      +                                                 C
//////////////////////////////////////////////////////////////////////////////////////
  0  0.000  1.000   .2900E+06      +                                                 C
  0  0.000  1.000   .2950E+06      +                                                 C
  0  0.000  1.000   .3000E+06      +                                                 C
  0  0.000  1.000   .3050E+06      +                                                 C
  0  0.000  1.000      INF         +                                                 C
---                                +    +    +    +    +    +    +    +    +    +    +
 20                                0         20        40        60        80       100
```

```
                                        **HISTOGRAM NUMBER  2**

                                              RNG TRK

OBSV   RELA   CUML      UPPER
FREQ   FREQ   FREQ   CELL LIMIT      0        20        40        60        80       100
                                     +    +    +    +    +    +    +    +    +    +    +
   0  0.000  0.000   .4050E+05       +                                                 +
   0  0.000  0.000   .4100E+05       +                                                 +
   0  0.000  0.000   .4150E+05       +                                                 +
   0  0.000  0.000   .4200E+05       +                                                 +
   0  0.000  0.000   .4250E+05       +                                                 +
   0  0.000  0.000   .4300E+05       +                                                 +
   0  0.000  0.000   .4350E+05       +                                                 +
   0  0.000  0.000   .4400E+05       +                                                 +
   0  0.000  0.000   .4450E+05       +                                                 +
   0  0.000  0.000   .4500E+05       +                                                 +
   0  0.000  0.000   .4550E+05       +                                                 +
   0  0.000  0.000   .4600E+05       +                                                 +
   0  0.000  0.000   .4650E+05       +                                                 +
   0  0.000  0.000   .4700E+05       +                                                 +
   0  0.000  0.000   .4750E+05       +                                                 +
   0  0.000  0.000   .4800E+05       +                                                 +
   0  0.000  0.000   .4850E+05       +                                                 +
   0  0.000  0.000   .4900E+05       +                                                 +
   0  0.000  0.000   .4950E+05       +                                                 +
   1   .050   .050   .5000E+05       +**                                               +
   0  0.000   .050   .5050E+05       + C                                               +
  19   .950  1.000      INF          +***********************************************  C
 ---                                 +    +    +    +    +    +    +    +    +    +    +
  20                                 0        20        40        60        80       100
```

```
                          **HISTOGRAM NUMBER  3**

                                RNG FIR

OBSV   RELA   CUML      UPPER
FREQ   FREQ   FREQ   CELL LIMIT   0         20        40        60        80        100
                                  +    +    +    +    +    +    +    +    +    +    +
   0  0.000  0.000   .1450E+05    +                                                 +
   0  0.000  0.000   .1550E+05    +                                                 +
   0  0.000  0.000   .1650E+05    +                                                 +
   0  0.000  0.000   .1750E+05    +                                                 +
   0  0.000  0.000   .1850E+05    +                                                 +
/////////////////////////////////////////////////////////////////////////////////////
   0  0.000  0.000   .3650E+05    +                                                 +
   0  0.000  0.000   .3750E+05    +                                                 +
   0  0.000  0.000   .3850E+05    +                                                 +
  13   .394   .394   .3950E+05    +********************                             +
  20   .606  1.000   .4050E+05    +******************************                   C
   0  0.000  1.000   .4150E+05    +                                                 C
   0  0.000  1.000   .4250E+05    +                                                 C
   0  0.000  1.000   .4350E+05    +                                                 C
   0  0.000  1.000   .4450E+05    +                                                 C
   0  0.000  1.000      INF       +                                                 C
 ---                              +    +    +    +    +    +    +    +    +    +    +
  33                              0         20        40        60        80        100
```

Appendix B

Calculation of the Intercept Point

Variables

t = missile flight time

$\overline{V}$ = velocity of the aircraft

$\overline{U}$ = velocity of the missile

v = speed of the aircraft

u = speed of the missile

$\overline{R}_o$ = initial position of the aircraft

$\overline{r}_o$ = initial position of the missile

$\overline{R},\overline{r}$ = position of the aircraft, missile at intercept

Diagrams

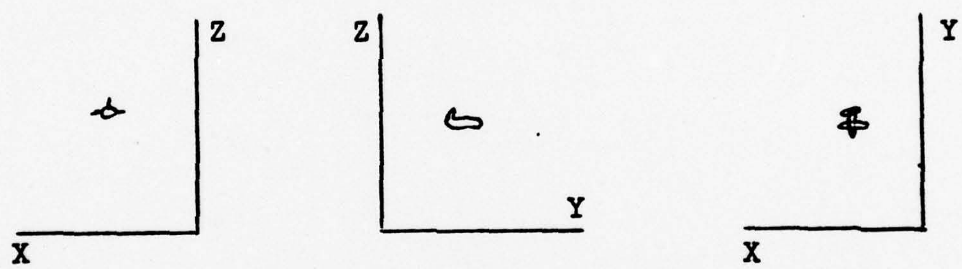


Diagram 1.

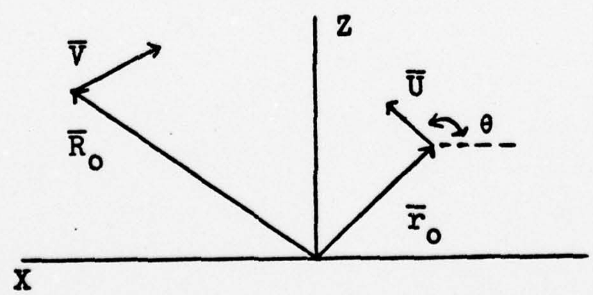


Diagram 2.

Solution

The initial positions of the aircraft and missile are given by

$$\overline{R}_o = X_o i + Y_o j + Z_o k$$
$$\overline{r}_o = x_o i + y_o j + z_o k$$

In a given time t, the aircraft and missile will move to new positions defined by

$$\overline{R} = \overline{R}_o + \overline{V}t$$
$$\overline{r} = \overline{r}_o + \overline{U}t$$

For intercept to occur,

$$\overline{R} = \overline{r}$$

Therefore,

$$\overline{R}_o + \overline{V}t = \overline{r}_o + \overline{U}t$$

or

$$\overline{R}_o - \overline{r}_o = (\overline{V} - \overline{U})t$$

Breaking these into components, we have

$$X_o i + Y_o j + Z_o k - x_o i - y_o j - z_o k = \overline{V}t - \overline{U}t$$

But the velocities can also be broken up into components, so

$$Vt - Ut = (V_x i + V_y j + V_z k - U_x i - U_y j - U_z k)t$$

From diagram 1,

$$U_x = u\cos\theta$$

$$U_z = u\sin\theta$$

Therefore, equating vectors and substituting, we have

$$X_o - x_o = (V_x - U_x)t = (V - u\cos\theta)t$$

$$Z_o - z_o = (V_z - U_z)t = (-u\sin\theta)t$$

since $V_z = 0$.

From the second equation,

$$t = \frac{Z_o - z_o}{-u\sin\theta}$$

From the first,

$$X_o - x_o = (V - u\cos\theta)\,\frac{(Z_o - z_o)}{(-u\sin\theta)}$$

Therefore,

$$(X_o - x_o)(-u\sin\theta) = (V - u\cos\theta)(Z_o - z_o)$$

But,

$$\sin\theta = (1 - \cos^2\theta)^{1/2}$$

so

$$(X_o - x_o)(-u)(1 - \cos^2\theta)^{1/2} = (V - u\cos\theta)(Z_o - z_o)$$

Squaring,

$$\frac{(X_o - x_o)^2}{(Z_o - z_o)^2}(u^2)(1 - \cos^2\theta) = V^2 - 2Vu\cos\theta + u^2\cos^2\theta$$

$$\frac{(X_o - x_o)^2}{(Z_o - z_o)^2}(u^2) - \frac{(X_o - x_o)^2}{(Z_o - z_o)^2}(u^2\cos^2\theta) = V^2 - 2Vu\cos\theta + u^2\cos^2\theta$$

$$\left(\left(\frac{(X_o - x_o)^2}{(Z_o - z_o)^2}u^2\right) + u^2\right)(\cos^2\theta) - 2Vu\cos\theta + V^2$$

$$\frac{(X_o - x_o)^2}{(Z_o - z_o)^2}u^2 = 0$$

Solve for $\cos\theta$ using the quadratic formula, with the following constants

$$-b = 2Vu$$

$$b^2 = 4V^2u^2$$

$$a = \frac{(X_o - x_o)^2}{(Z_o - z_o)^2}u^2 + u^2$$

$$c = V^2 - \frac{(X_o - x_o)^2}{(Z_o - z_o)^2}u^2$$

VITA

James Robert Penick was born on 23 Feb. 1950, in San Diego, Calif. A graduate of Johnson City, Texas, high school, he attended Southwest Texas State University, beginning in 1969. He received the degree of Bachelor of Science in Aug. 1971. He then attended OTS at Lackland AFB, Texas, and was commissioned a 2nd Lt. on 17 Dec. 1971. His first assignment was to Mather AFB, Calif., where he received training as a navigator and electronic warfare officer. Upon graduation in Sept. 1973, he was assigned to the 716th Bomb Squadron, 449th Bomb Wing, Kincheloe AFB, Mich. He served there until entering the Air Force Institute of Technology School of Engineering in May, 1976.

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Laser Engagement Analysis
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Laser Countermeasures
Electronic Warfare

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Contains data on construction of a computer program to analyze optical engagements. Aircraft flies over threat, which detects, tracks, and fires missiles at the aircraft. All input parameters are flexible so as to allow simulation of any threat vs any aircraft with appropriate data. Parameters used are not specific to any one system. Contains flowcharts, diagrams of scenarios, results, and calculations of the intercept point.

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